Wave-convection interaction
or
‘divergent manifold weather’

phenomena, predictability, parts, & prospects for parameterization

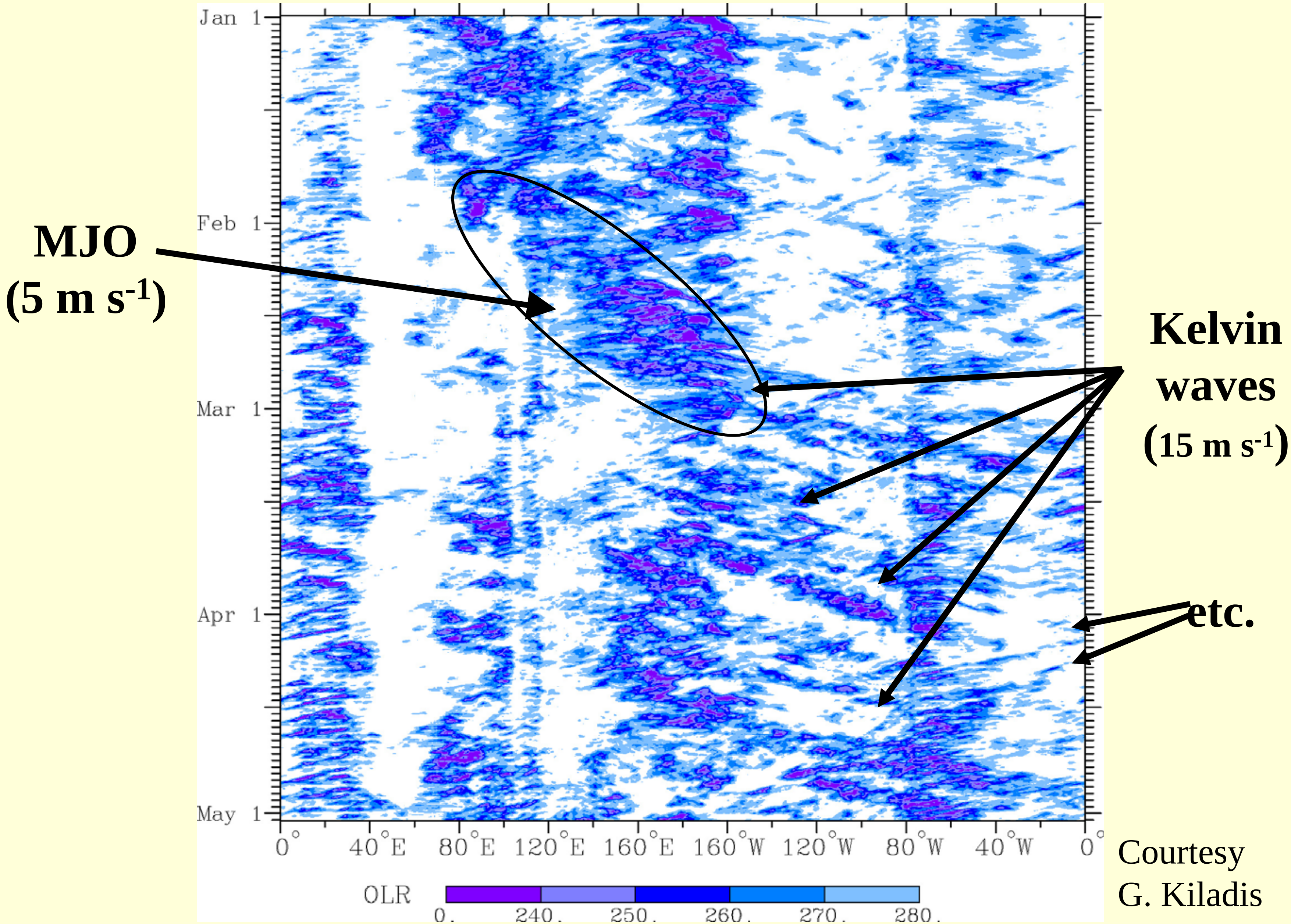
Brian Mapes
Rosenstiel School (RSMAS)
University of Miami

ECMWF Seminar Sept 2008

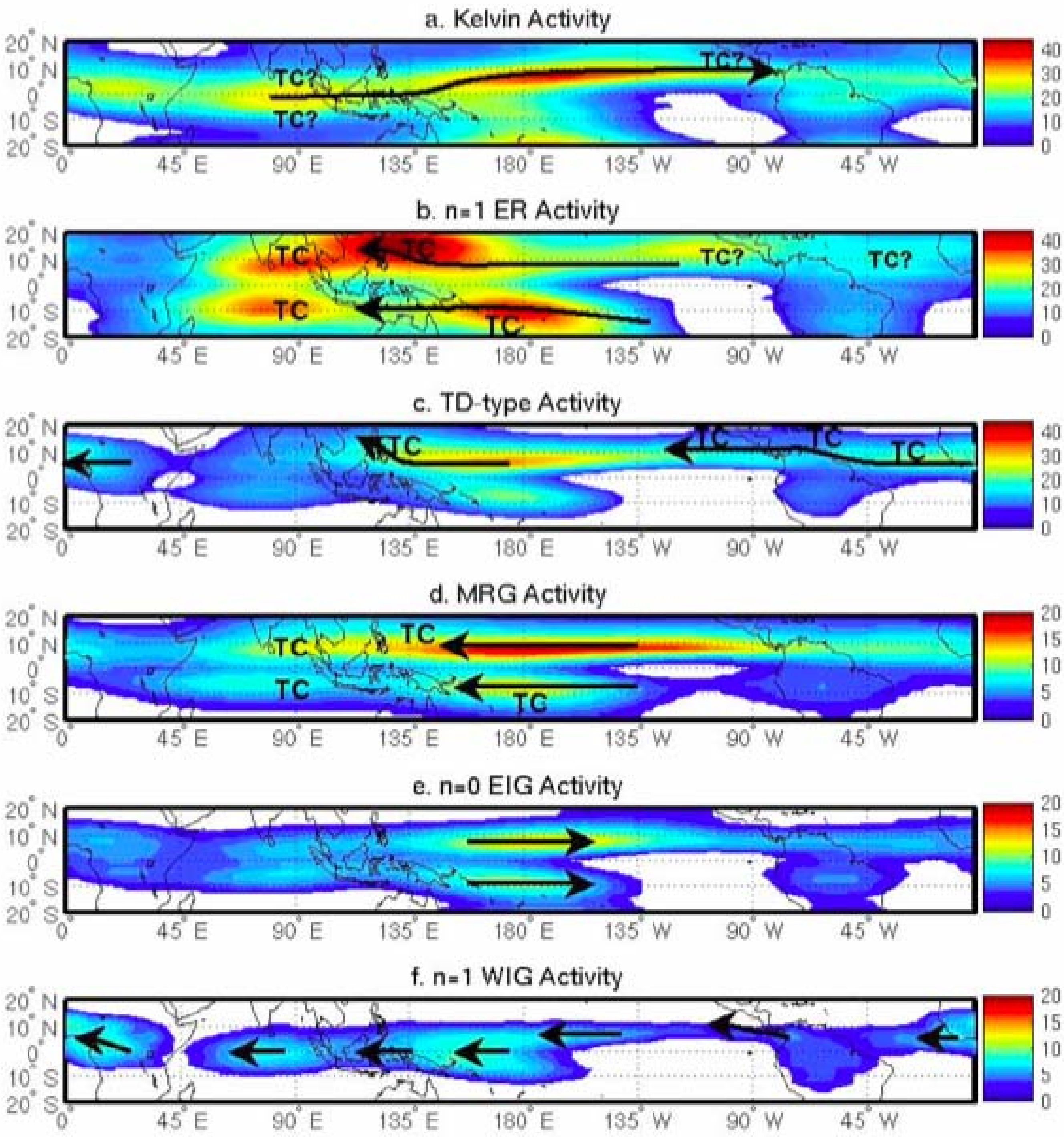
1. Coupled wave-convection phenomena:
   - Tropical: Kelvin and friends (MJO is different)?
   - (midlatitude too: US summer)
2. Simulability with explicit convection models
3. Predictability, inferred from persistence &
   - Medium Range (2 weeks) even for Kelvin waves
4. Mechanisms and issues for parameterization
   - Ingredients
     - convection & cloud types (shallow-deep-stratiform)
   - Relationships
     - progression (on many time scales)
5. Meta-parameterization: an "ORG" scheme
   - a binder/wrapper scheme for individual processes

Many scales in space-time: tropical waves

Time–longitude CLAUS IR (2.5S–7.5N), Jan–Apr 1987



Courtesy
G. Kiladis



Tropical wave activity

Kiladis et al.

2008 or 9

Reviews of Geophysics

In final revision

3 hourly satellite imagery since forever

Satellite Data > Global ISCCP B1 Browse System

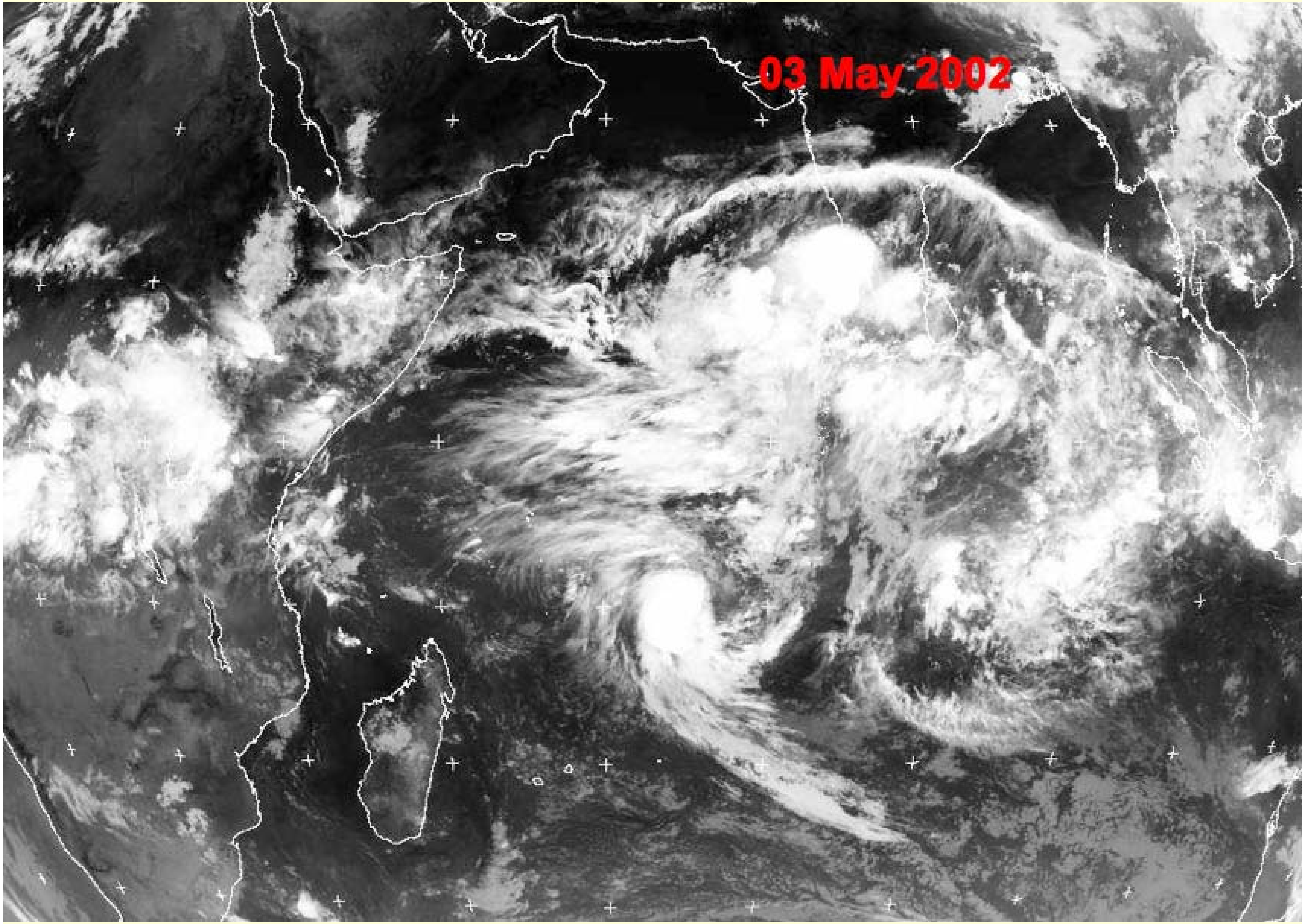
GIBBS: Global ISCCP B1 Browse System

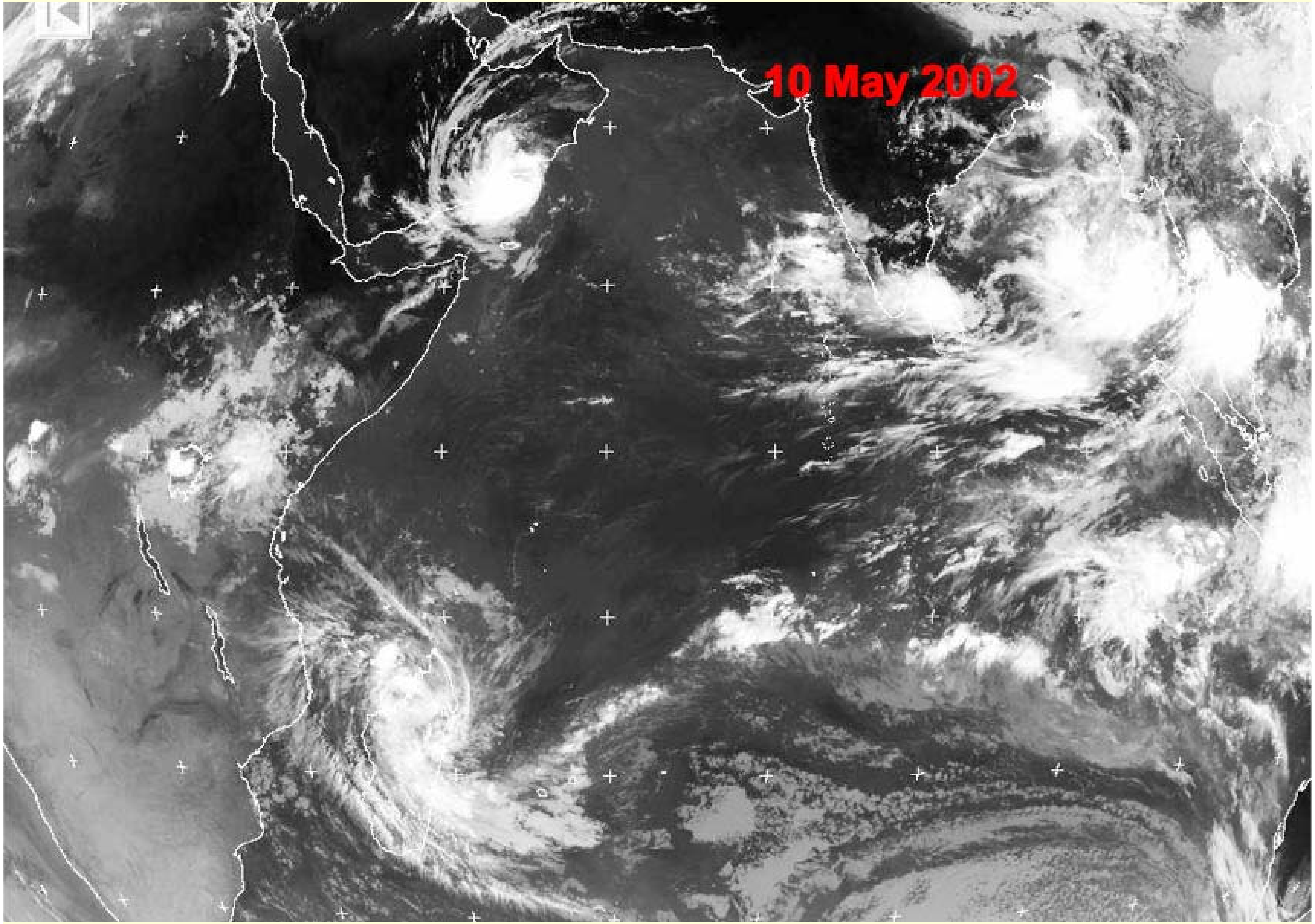
Select year...		YEAR (# of images)		1974 (985)	1975 (0)	1976 (2)	1977 (0)	1978 (5394)	1979 (19361)
1980 (10467)	1981 (21626)	1982 (30417)	1983 (31581)	1984 (17181)	1985 (16150)	1986 (15779)	1987 (20175)	1988 (19349)	1989 (15903)
1990 (17339)	1991 (17559)	1992 (20419)	1993 (27079)	1994 (26505)	1995 (25309)	1996 (31851)	1997 (32264)	1998 (36901)	1999 (41512)
2000 (42348)	2001 (42484)	2002 (42362)	2003 (42376)	2004 (43235)	2005 (55018)	2006 (58140)	2007 (49085)	2008 (25776)	

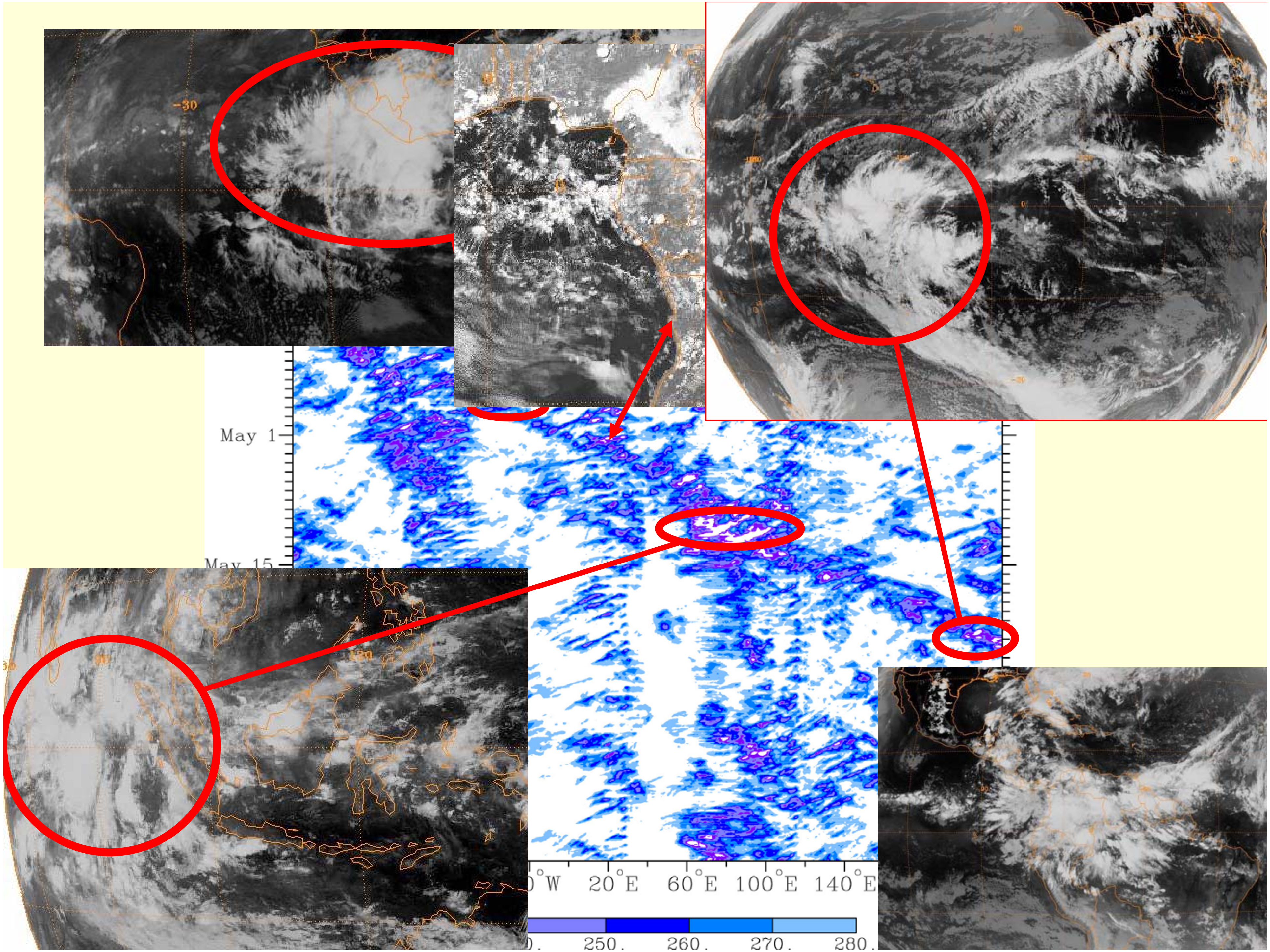
901932 total satellite images

Last Updated: Wed Aug 27 2008, 03:21:11 EDT

http://www.ncdc.noaa.gov/gibbs/


03 May 2002

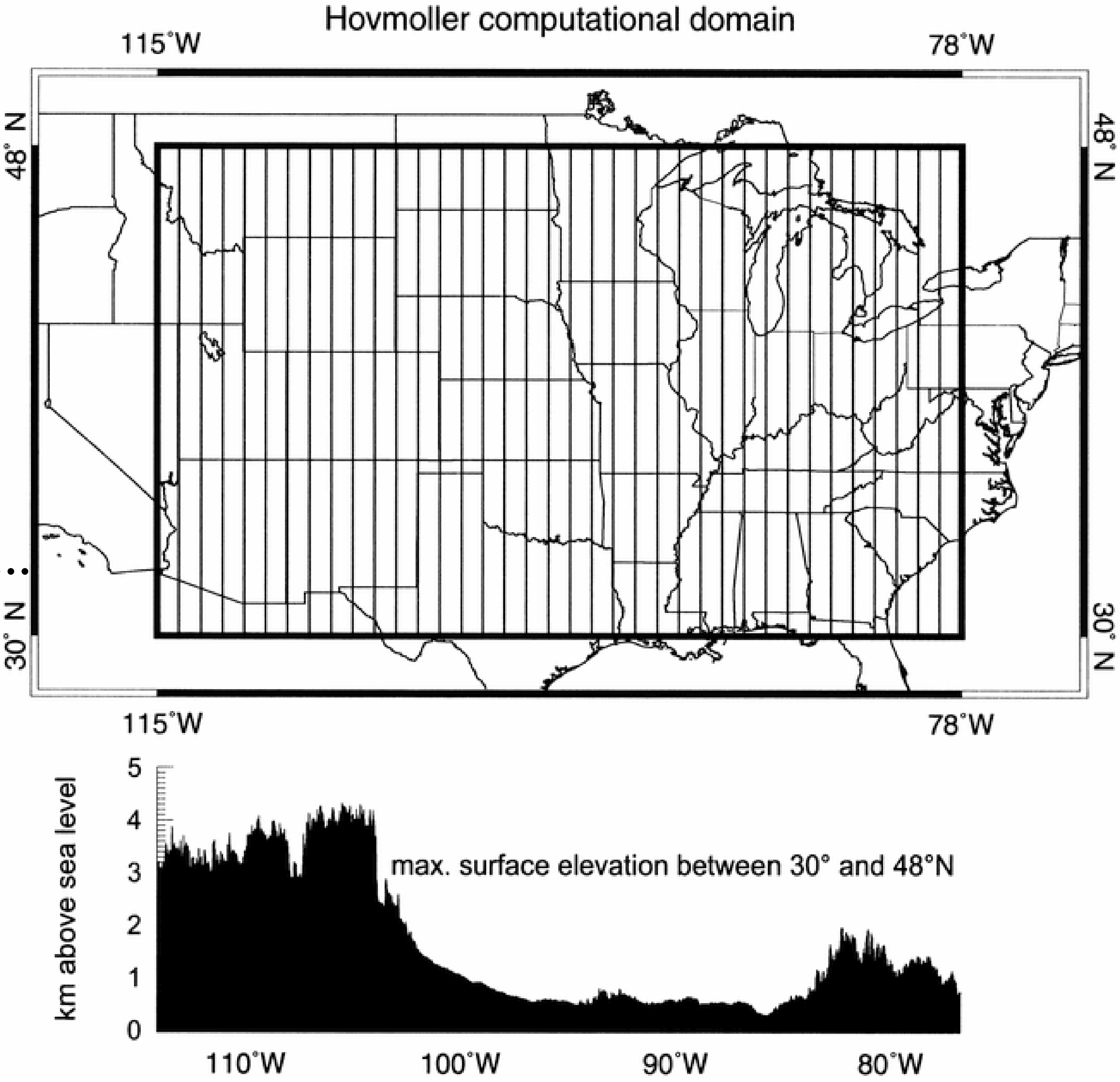

10 May 2002



May 1
May 15
20°E
60°E
100°E
140°E
250.
260.
270.
280.

Wavy convective variability is not just a tropical phenomenon…

Carbone et al. 2003



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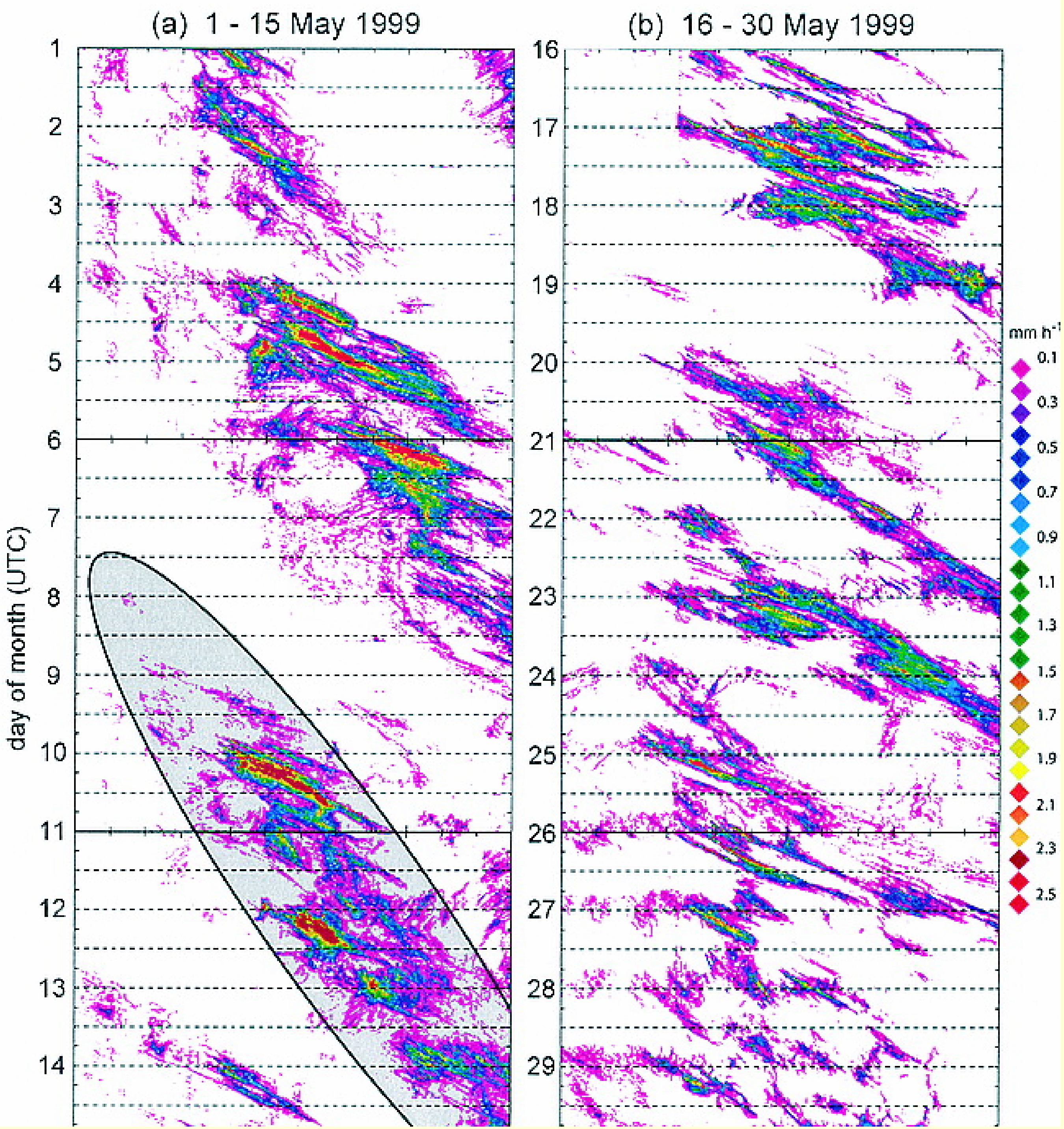
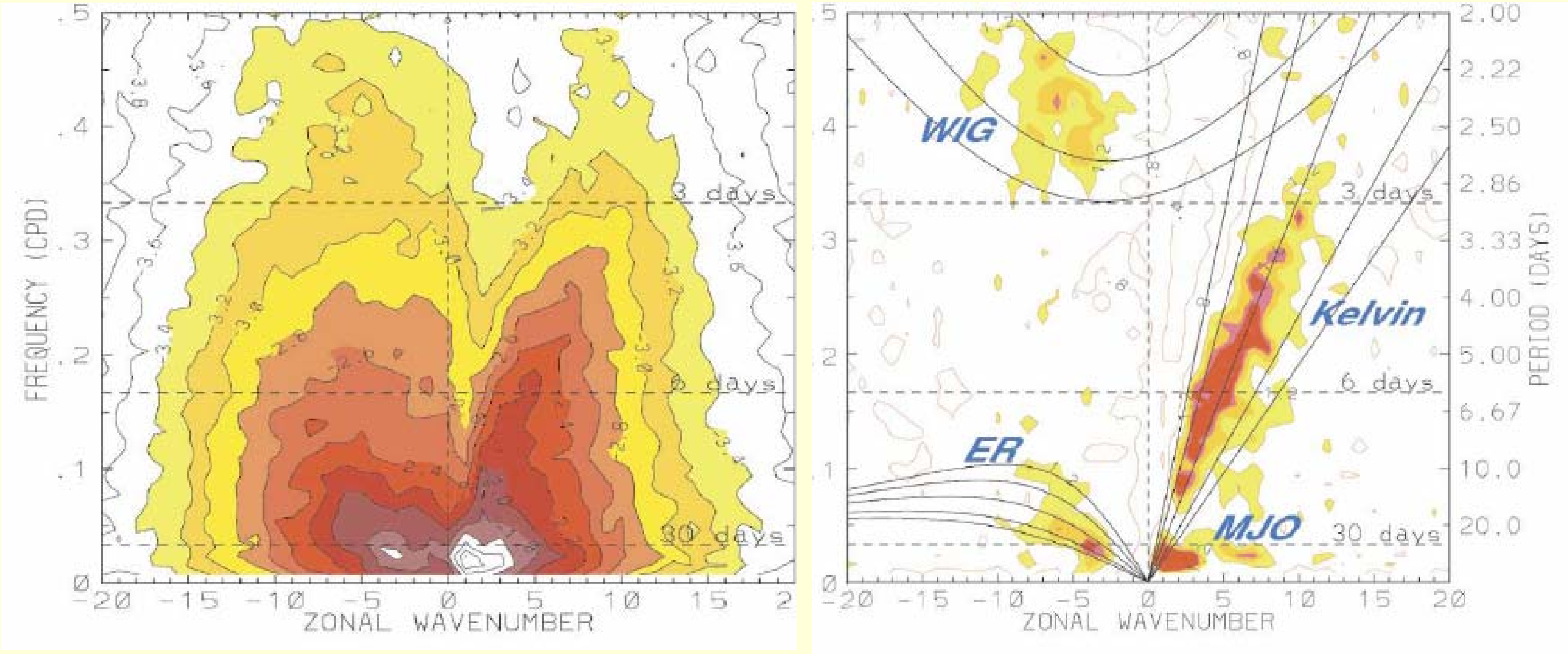


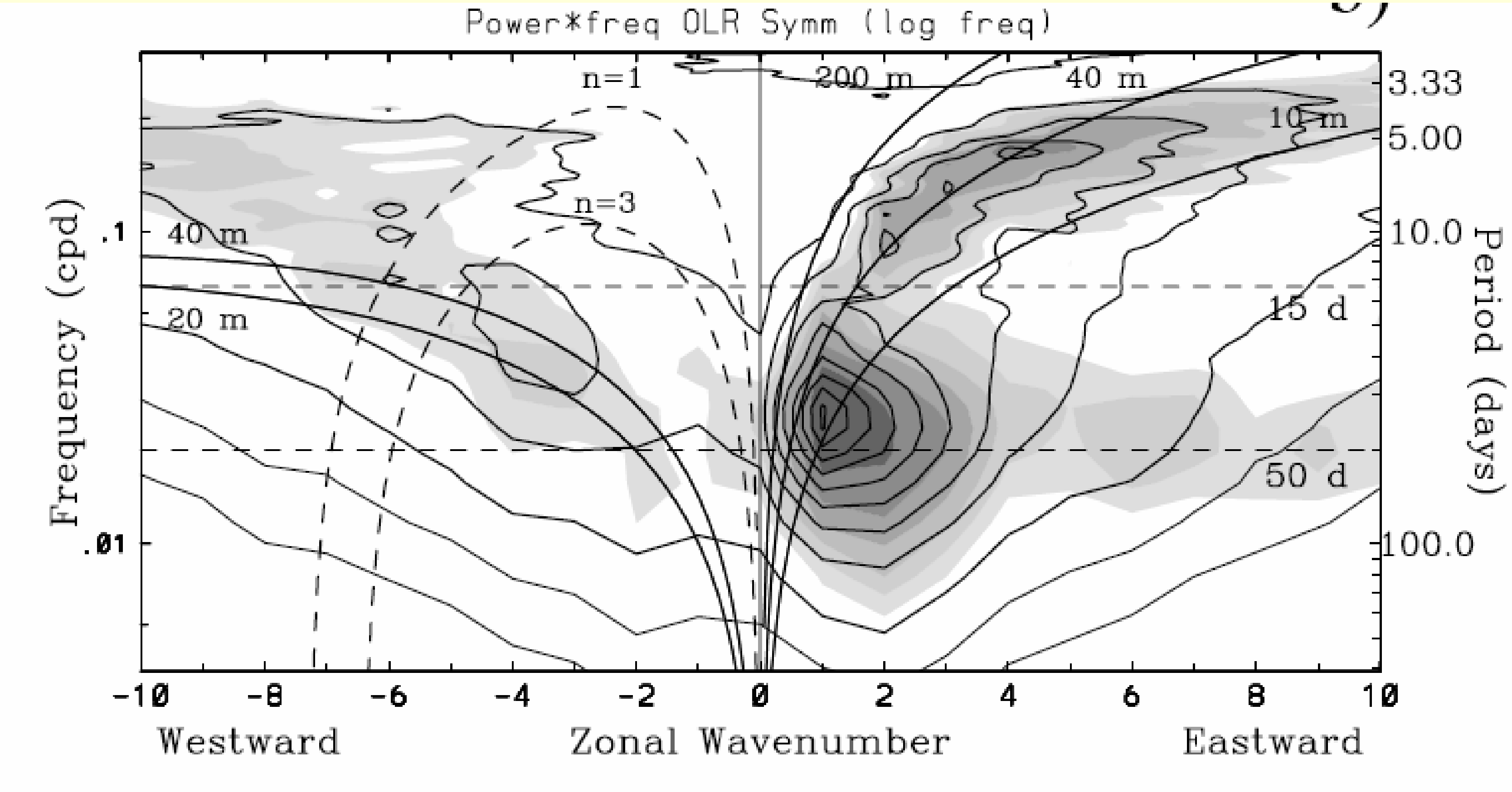
Power spectrum of symm. tropical OLR

MJO + linear wave enhancements
on red noise background

- Takayabu; Wheeler and Kiladis 1999; Lin et al 2006 (this fig)

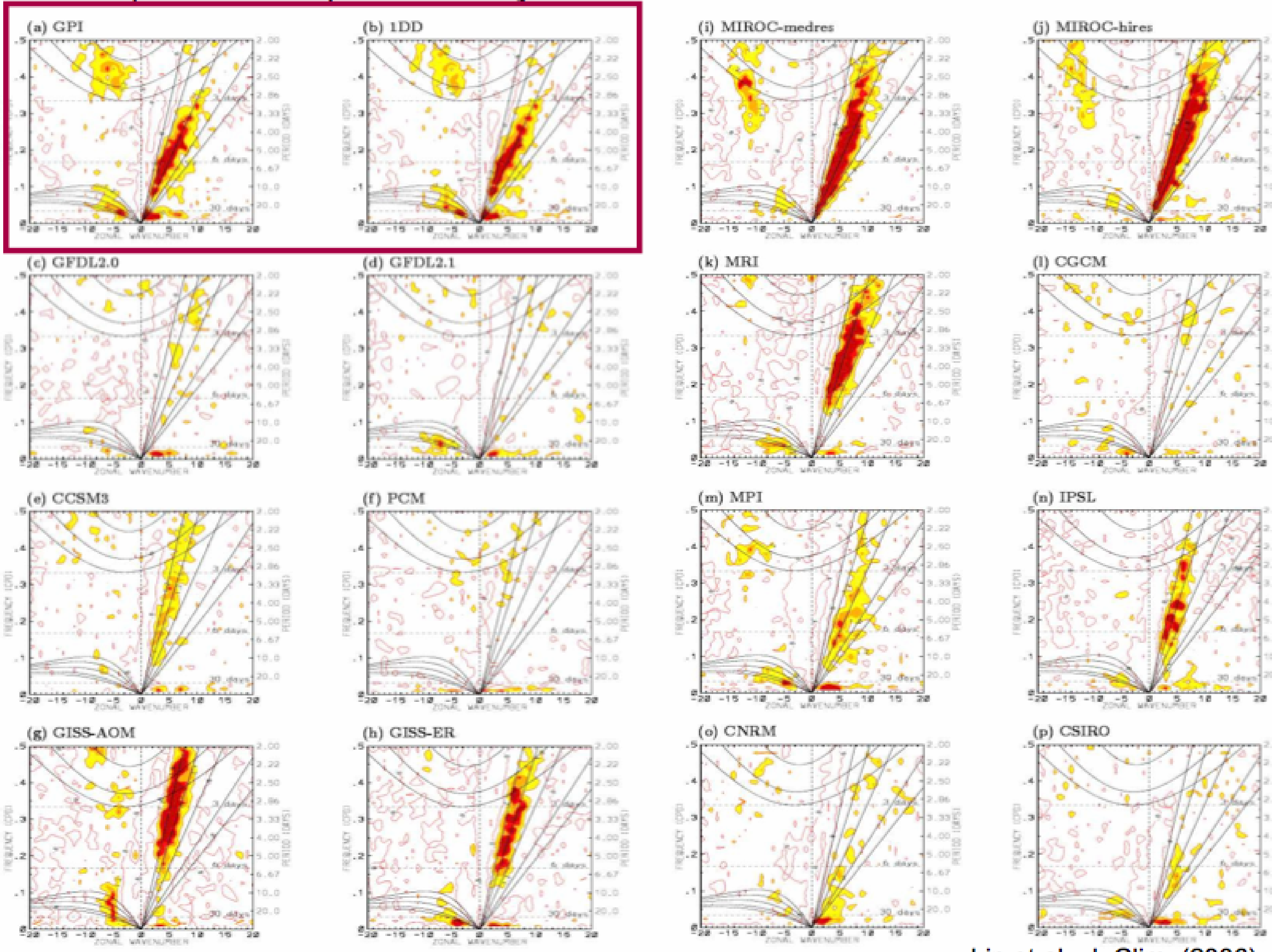


Closer to raw: P*freq vs. log freq (Hendon and Wheeler 2008)



Hendon and Wheeler 2008 JAS

Space-time spectra for symmetric waves from IPCC AR4 models



Lin et al., J. Clim. (2006)

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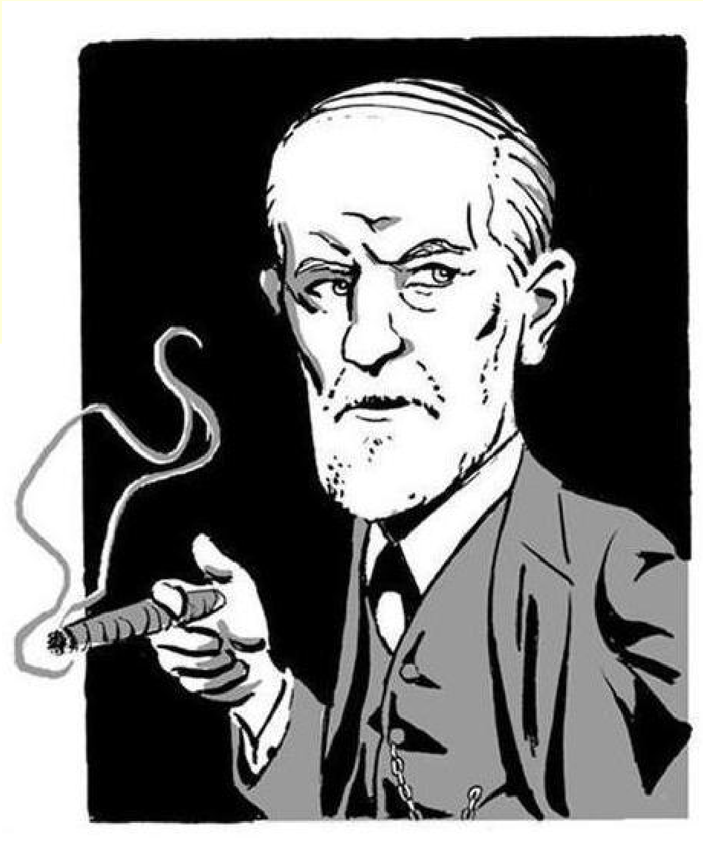
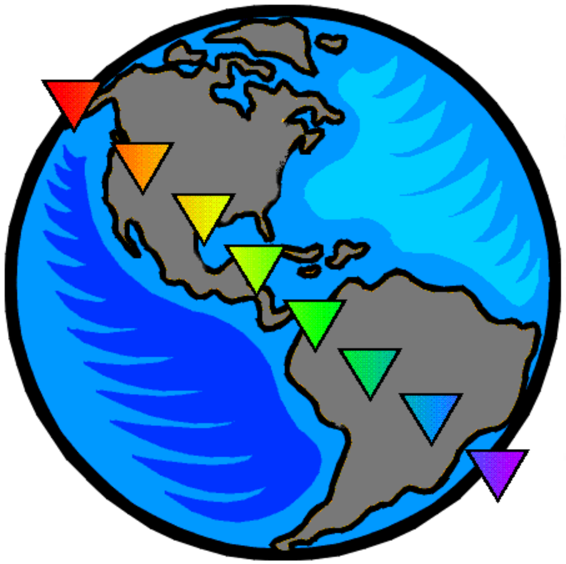
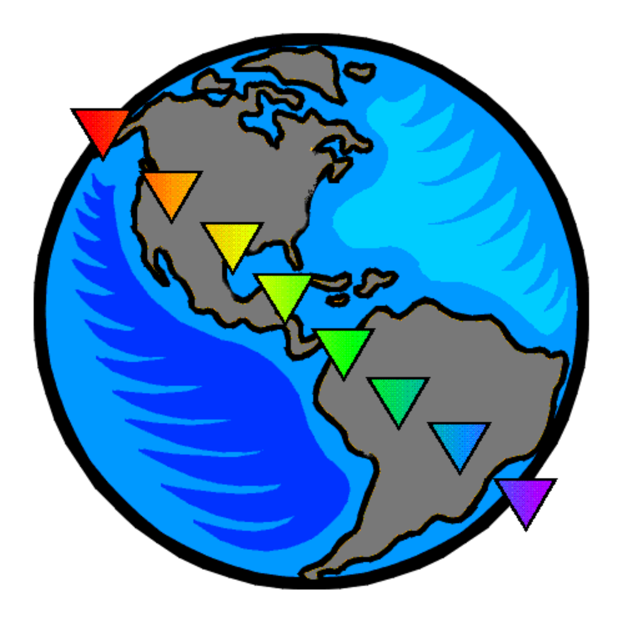
Meteorology's ancient dream is coming true

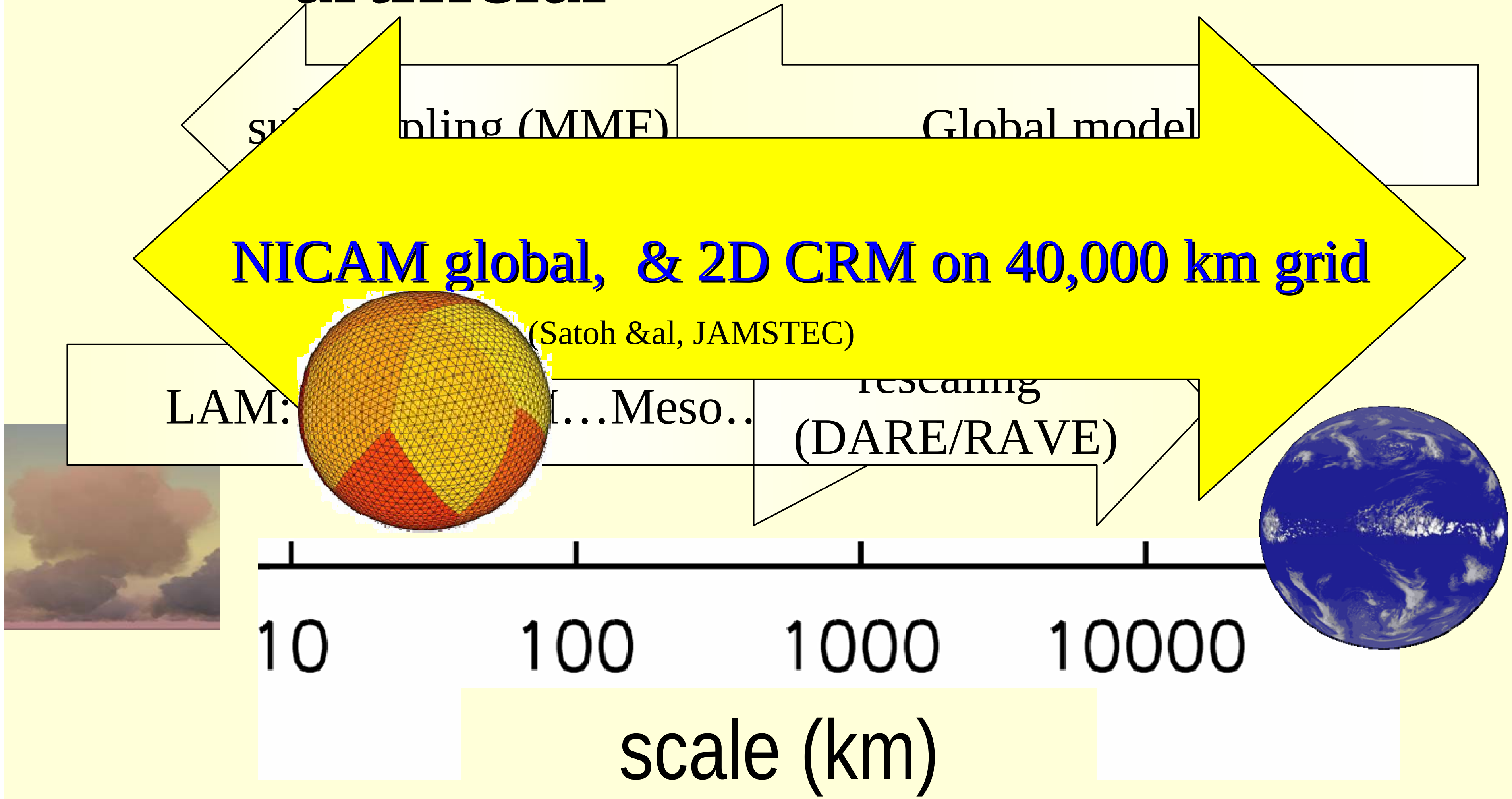




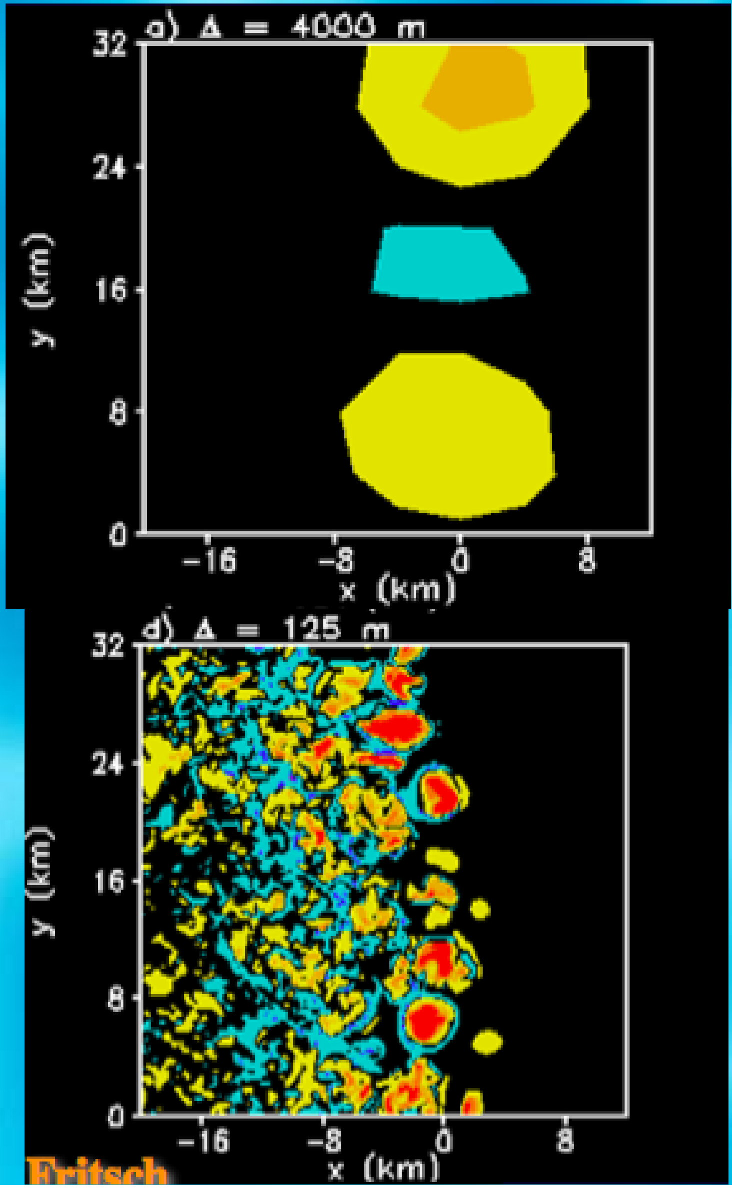
for lumpers as well as splitters

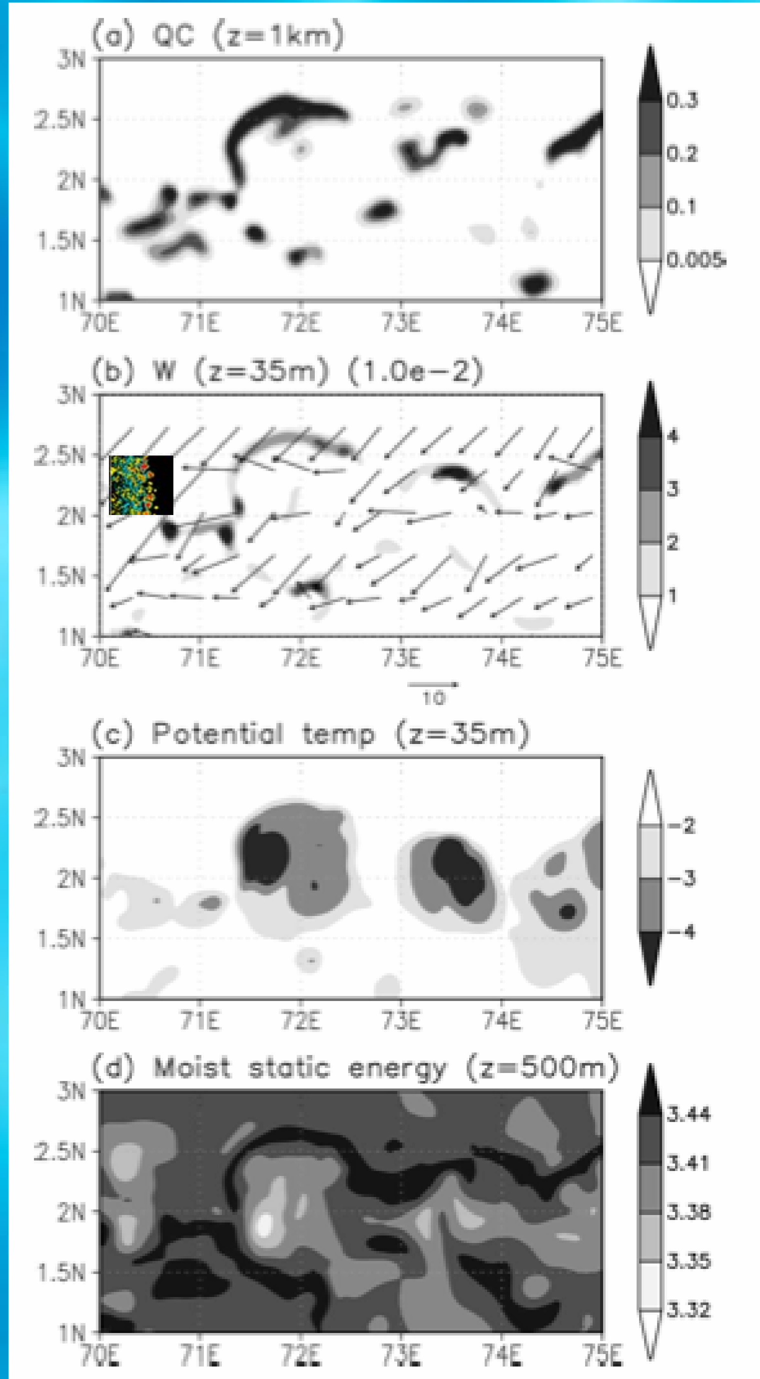


Erasing the field’s old artificial scale boundaries



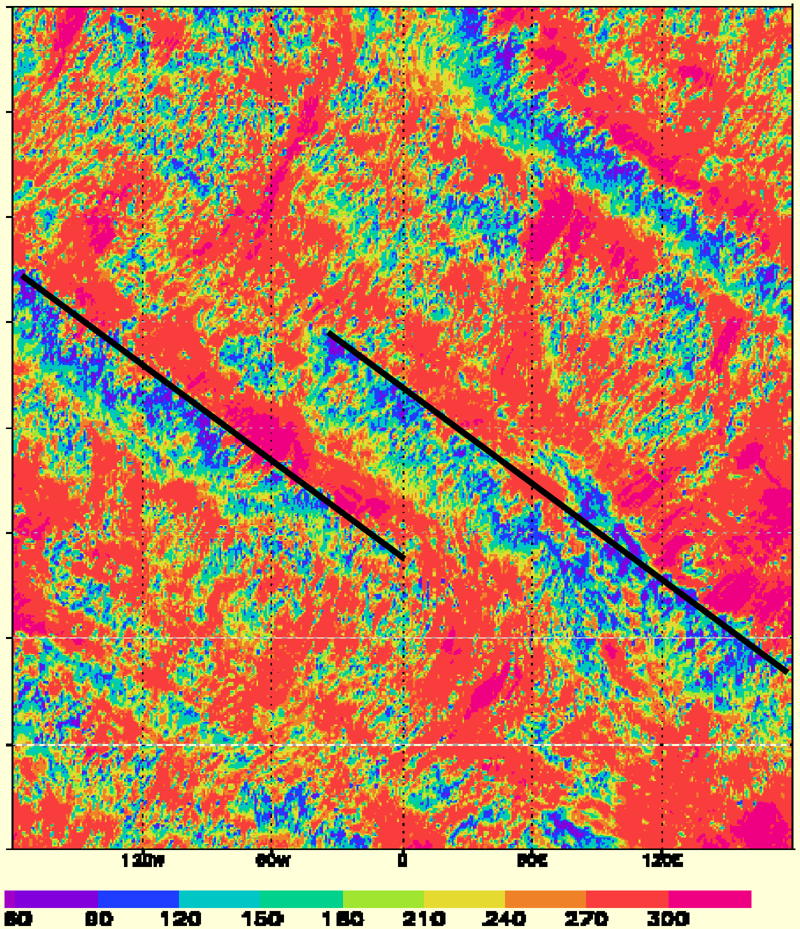
NICAM: Fine enough?





Bryan and Fritsch 2000

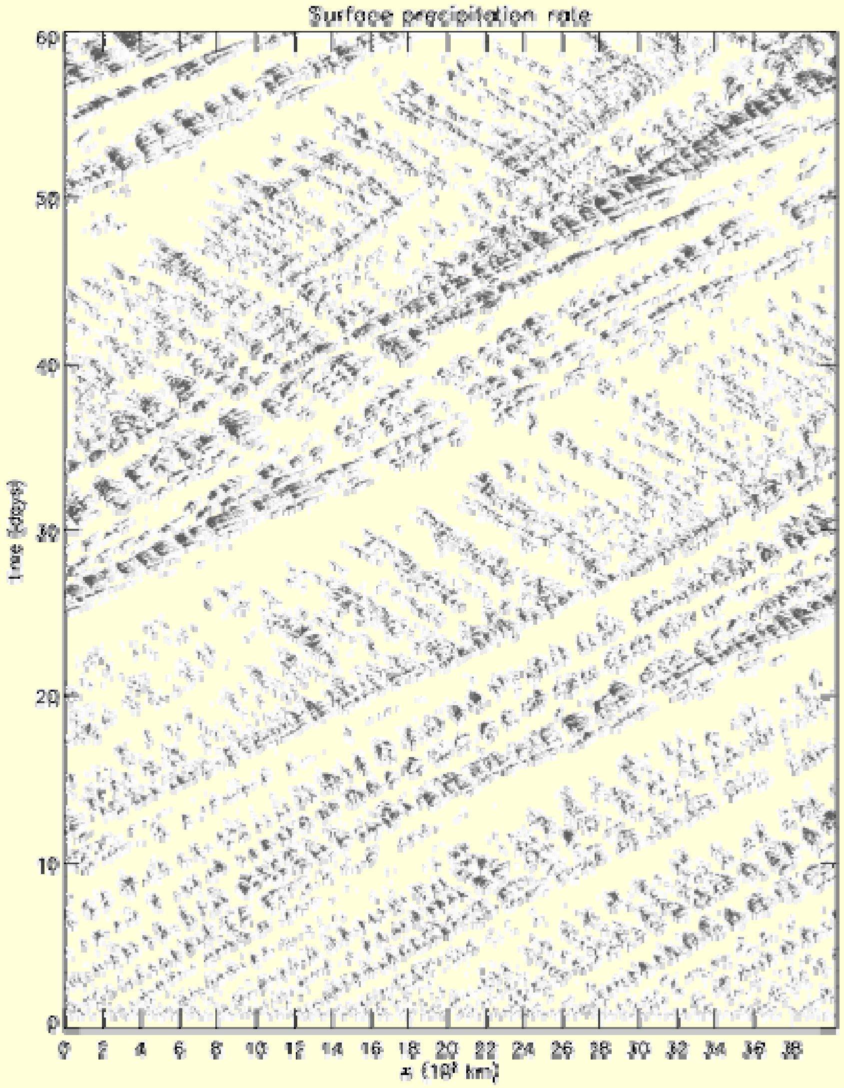
NICAM tropical belt (aqua) 3.5, 7, &14km
and Stefan Tulich's 2D CRM runs 2km



<------time

longitude

NICAM OLR, T. Nasuno



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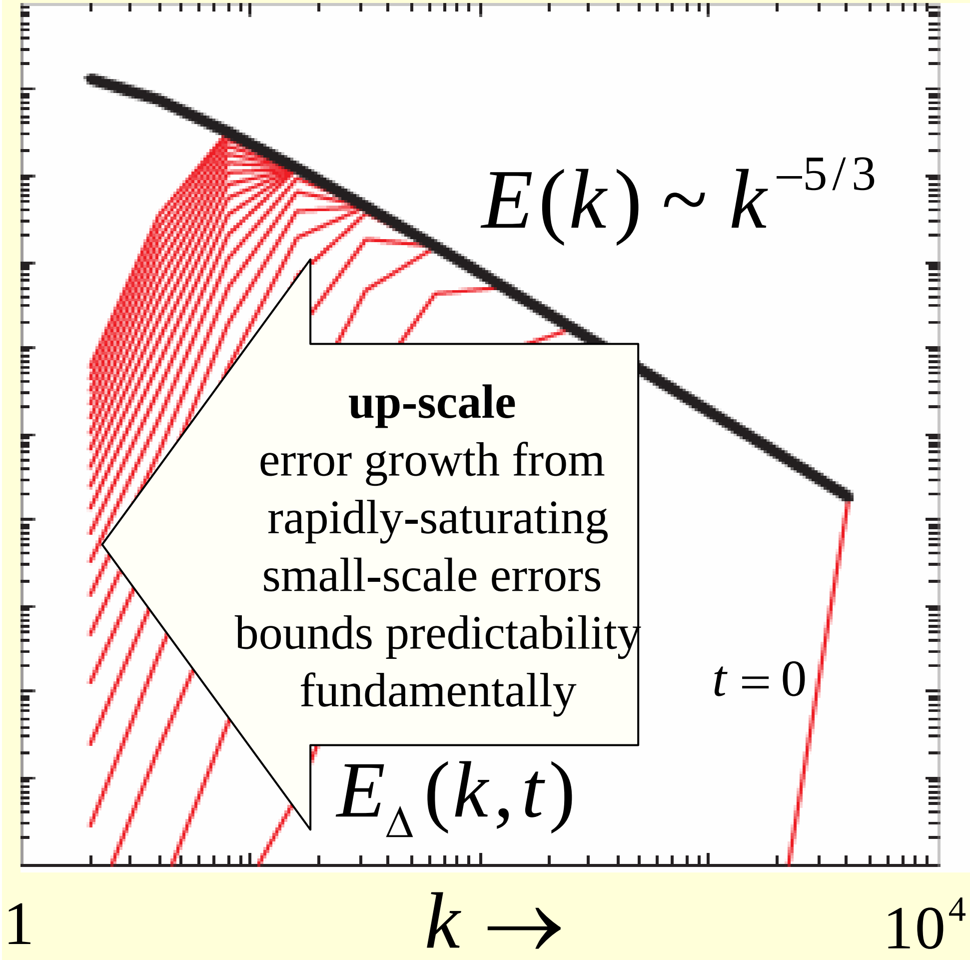
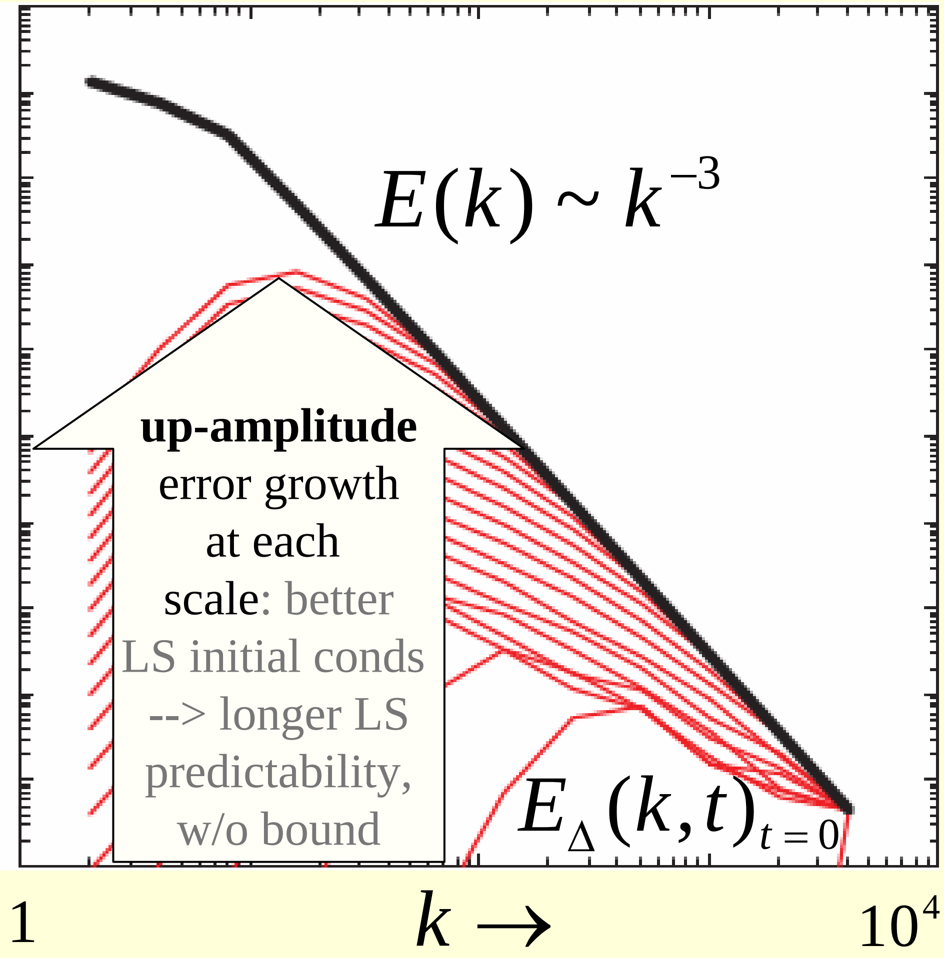
Revisited by Rotunno and Snyder 2008 JAS

SQG^* — *Limited Predictability*



$2D$ — *Unlimited Predictability*

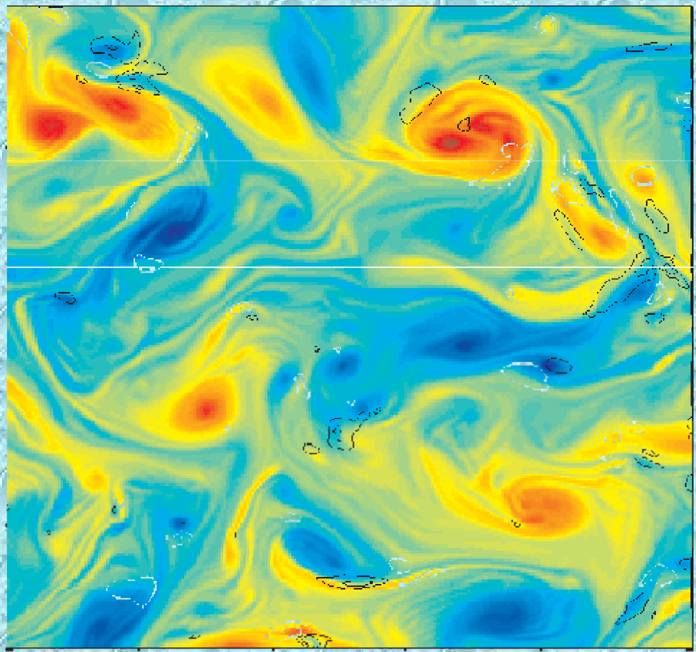


*SQG=Surface QG , Blumen(*JAS* 1982)
Pierrehumbert, Held and Swanson (*CSF* 1994)

Slide from Rich Rotunno

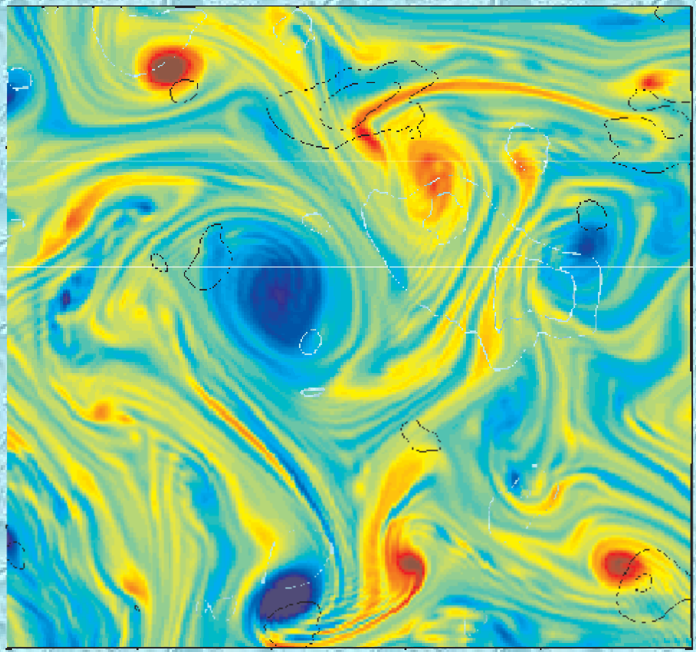
In physical space…

SQG



Limited Predictability

2D

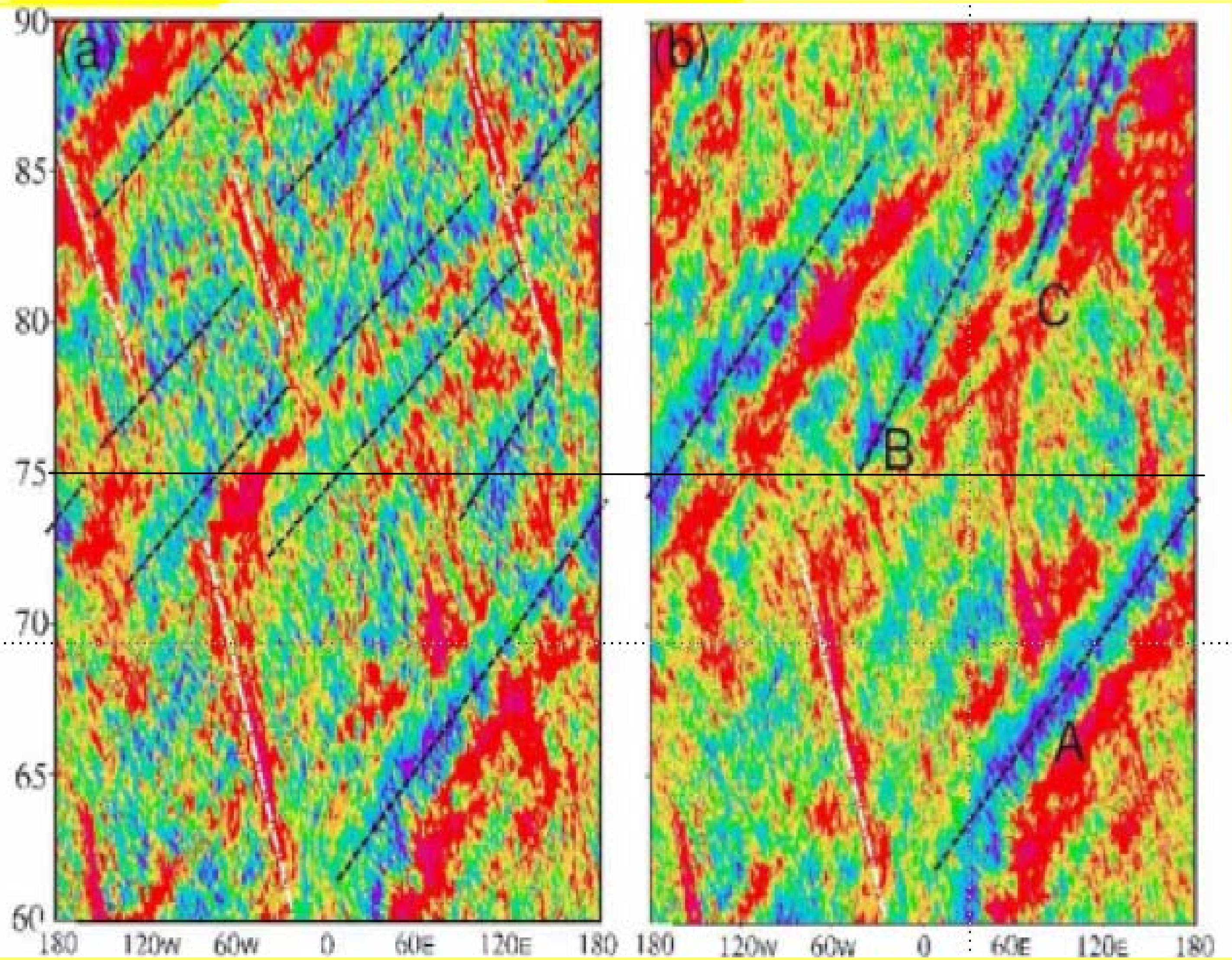


Unlimited Predictability

Vorticity fields

Slide from Rich Rotunno

Hovmoller diagrams of OLR (2S-2N)



2 NICAM global explicit-convection runs

-from almost identical initial conditions-

LS Kelvin waves come to differ after about 2 weeks.

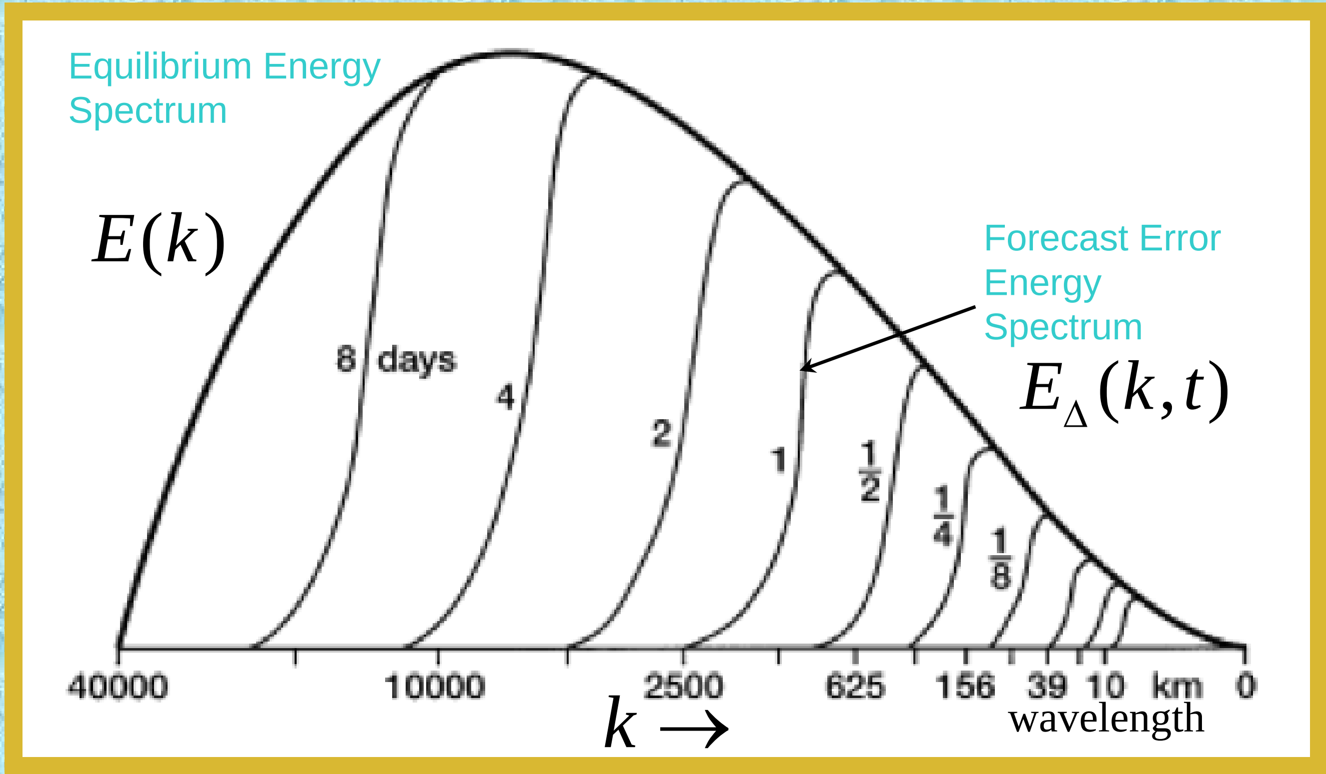
Nasuno et al. 2007 JAS

(an interpretive complication: resolution differs..., not just initial state)

Traditional predictability study system:

rotational manifold flow (2D or QG turbulence)

The Predictability of Flows with Many Scales of Motion



Lorenz (*Tellus* 1969)

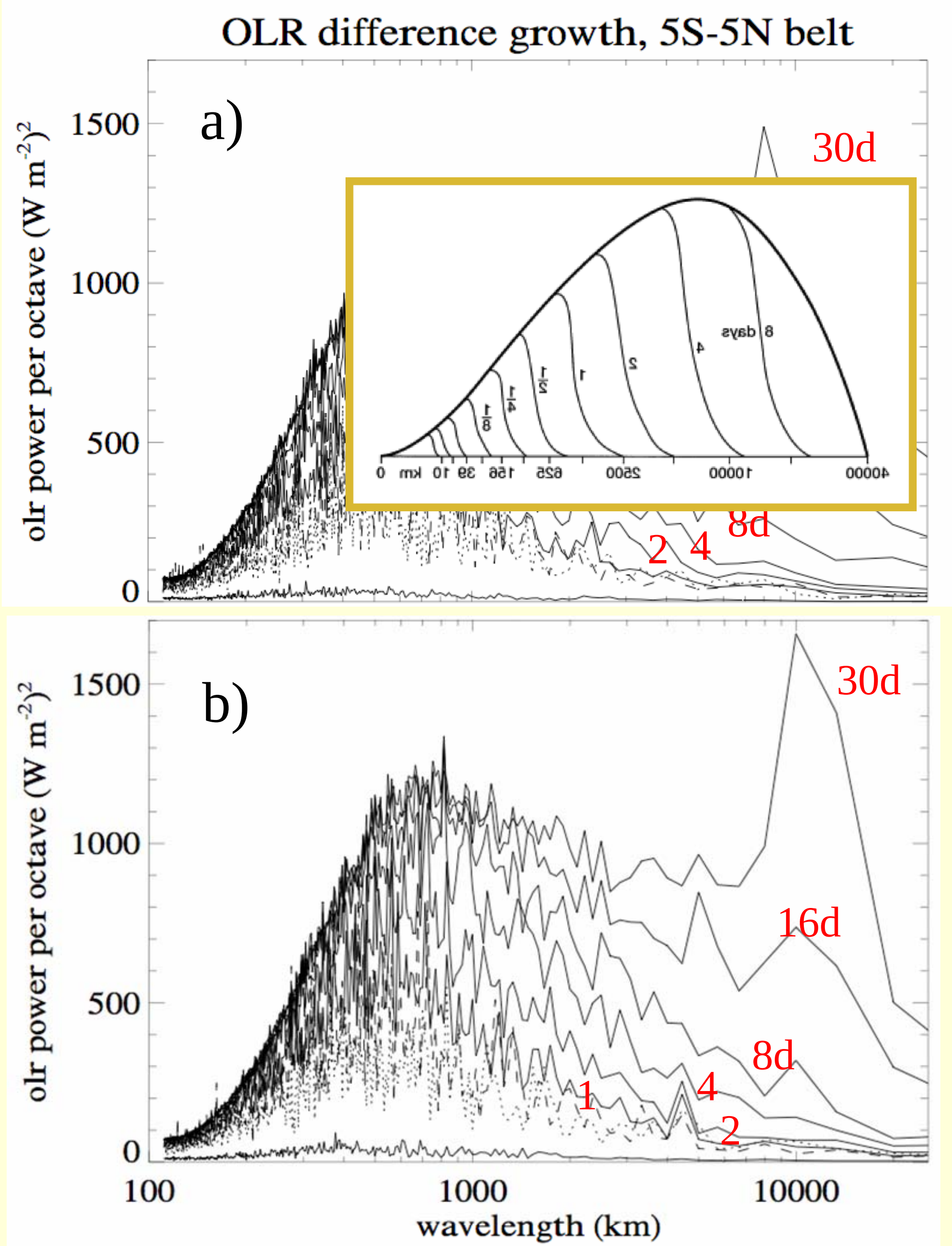
Slide from Rich Rotunno -- fig. also in Tribbia and Ehrendorfer (2004)

Difference growth by scale

(Lorenz's diagram, backward)

- difference growth in 2 realizations of NICAM run-pairs with near-identical initial conditions

Mapes et al. 2008 JMSJ in press



OLR animation

QuickTime™ and a
Cinepak decompressor
are needed to see this picture.

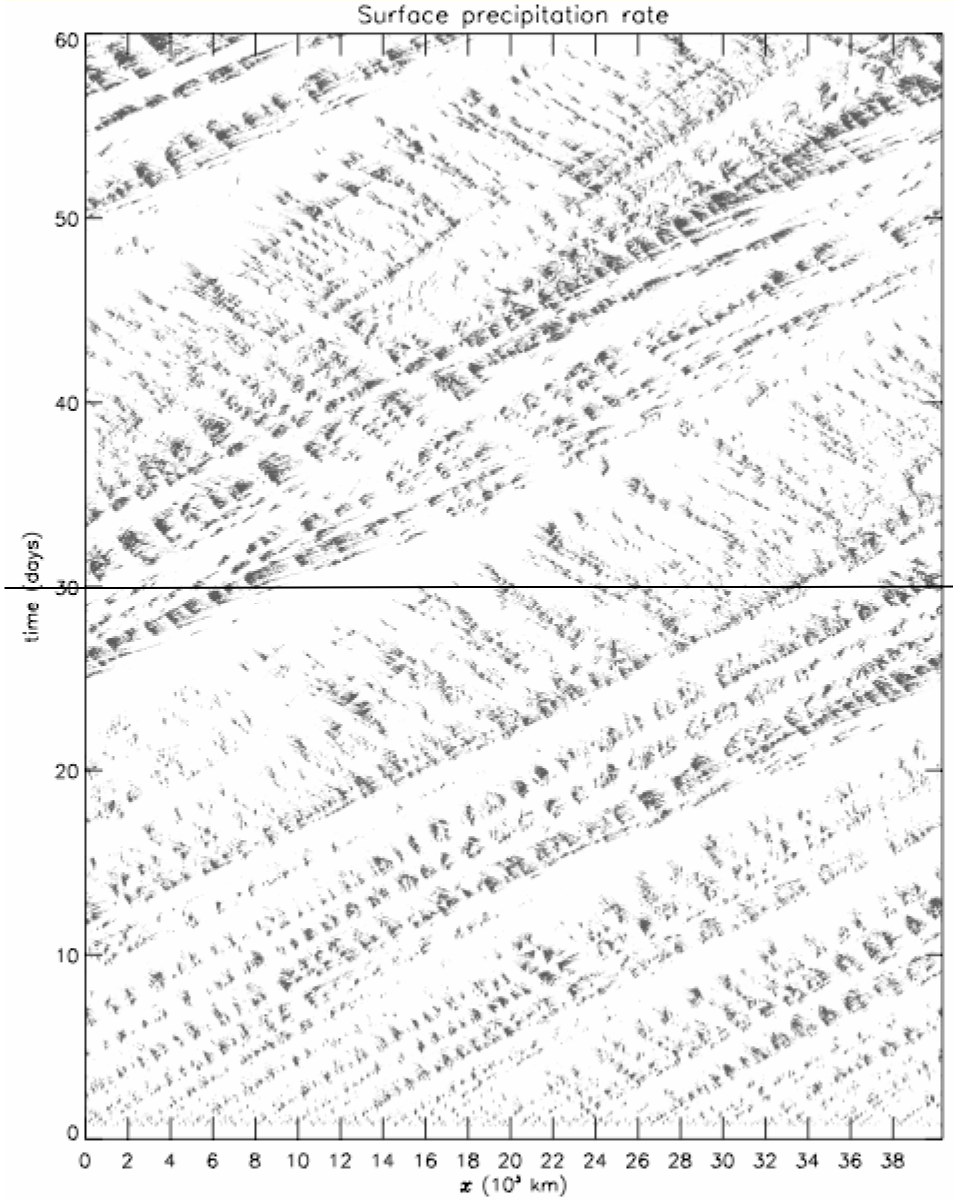
Q: What sets this apparent ~2-week tropical wave predictability limit?

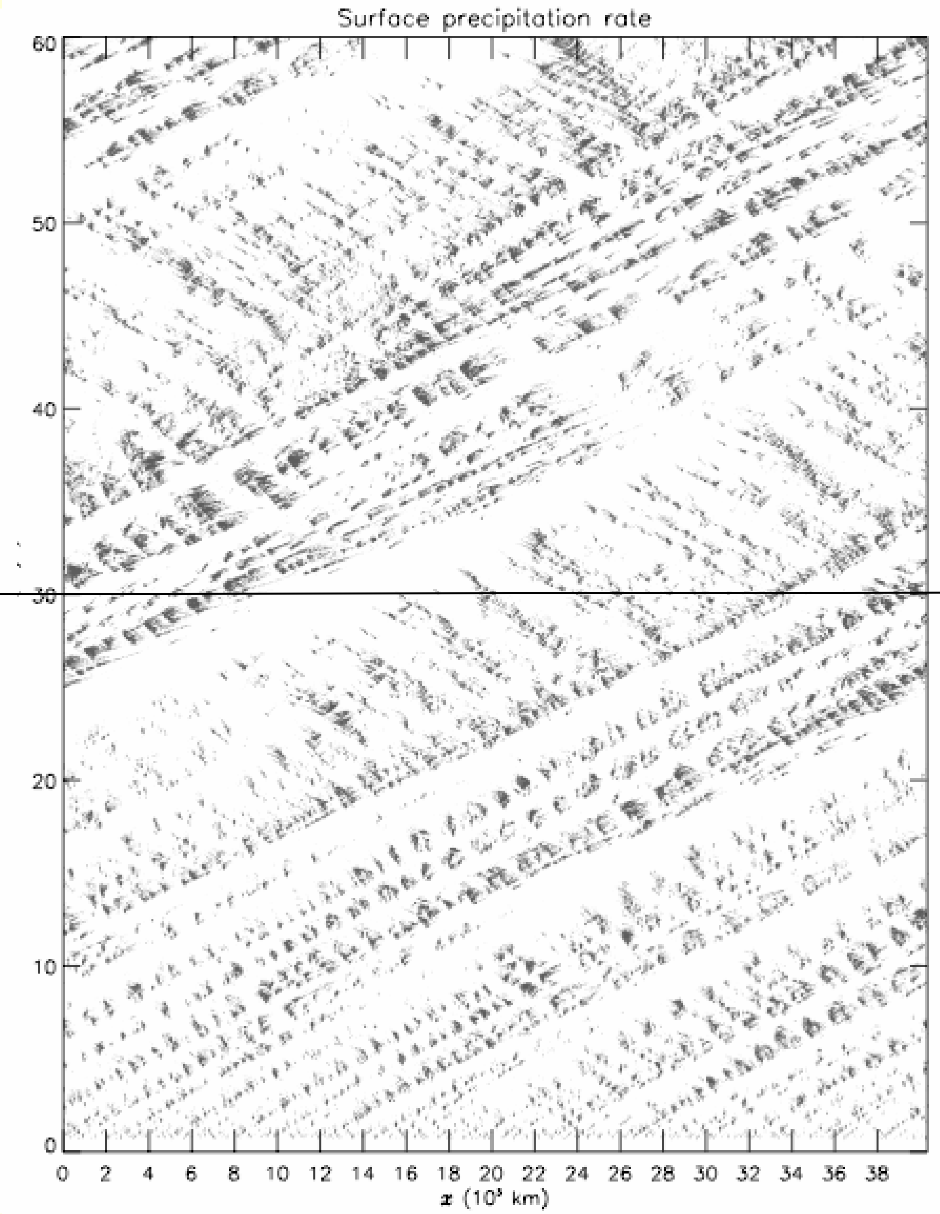
1. **Interactions with midlatitude synoptic swirls (with their well known ~2 week predictability limit)?**

or

1. **Upscale growth (chaos) within the mostly-divergent wave-convection dynamics of the tropical belt?**

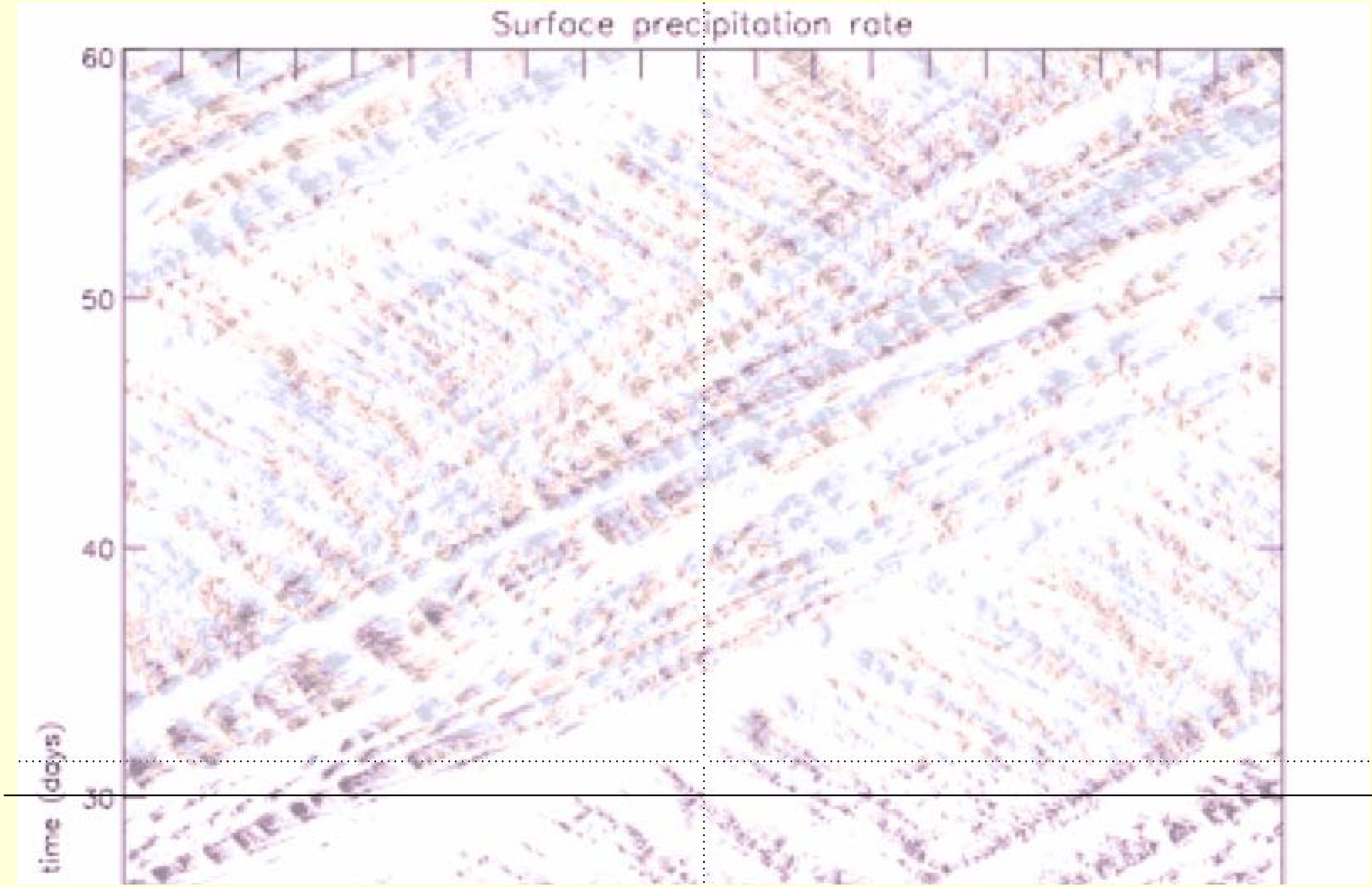
2D CRM a clean test: no horizontal swirls





A: 'Divergent manifold chaos' suffices to limit LS predictability to ~ 2 weeks

i.e., diffs still grow to near saturation over ~2 weeks in 2D



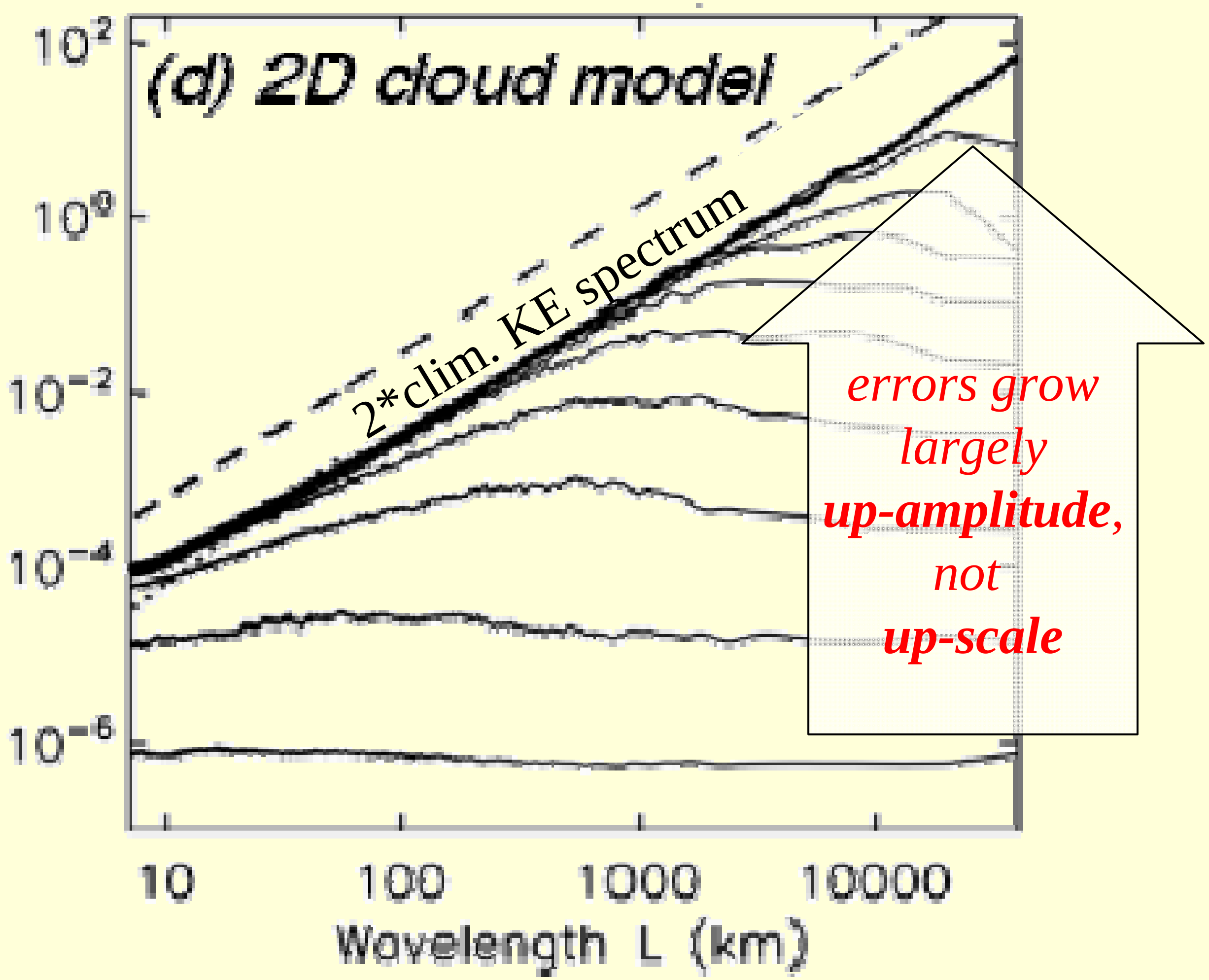
Mapes et al. JMSJ 2008 in press

Spectral view of predictability: 2D CRM layer-mean KE

Power at each wavelength

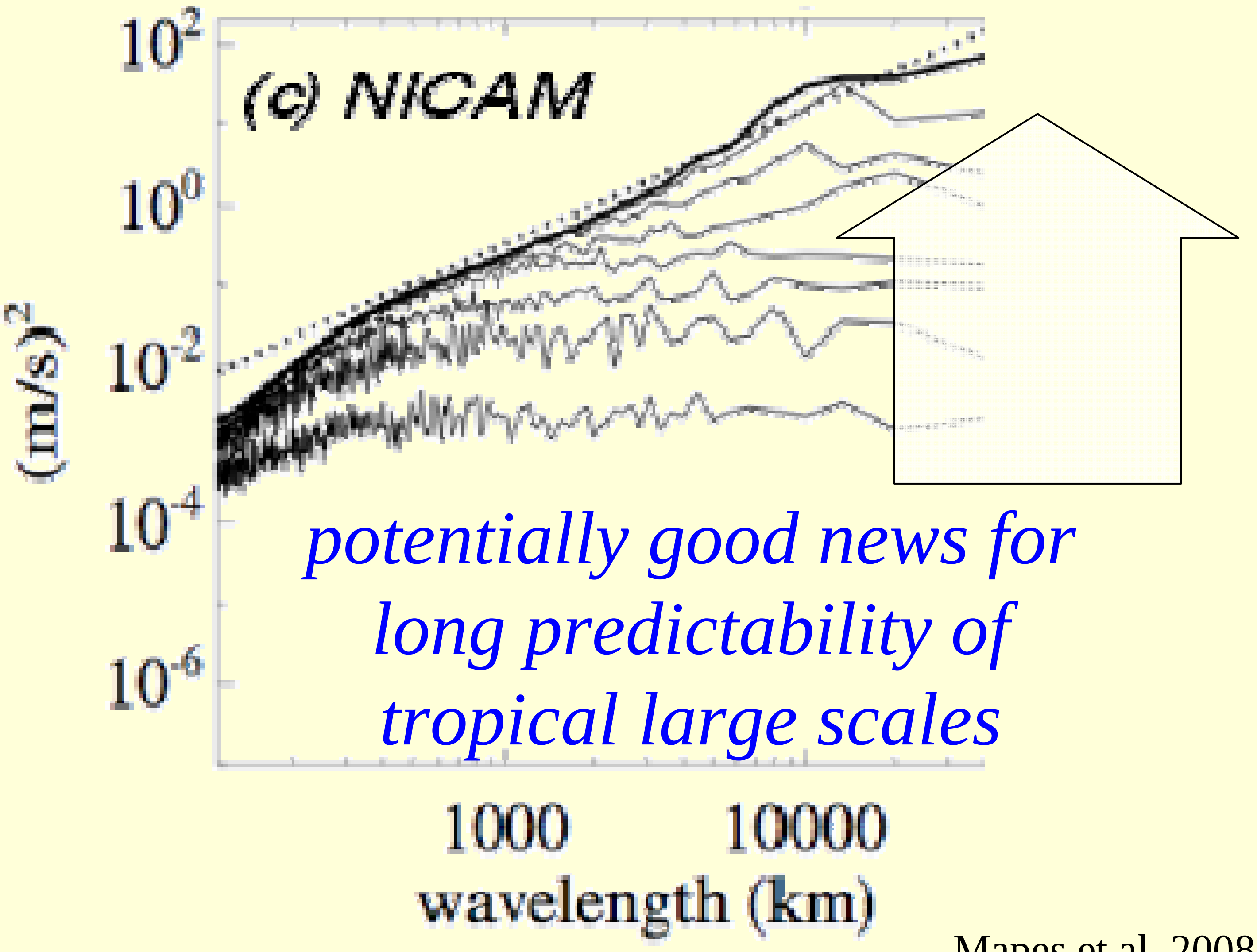
(wind variance)

= KE



Mapes et al. 2008 JMSJ

Spectral view of predictability:
NICAM u @ 12km altitude

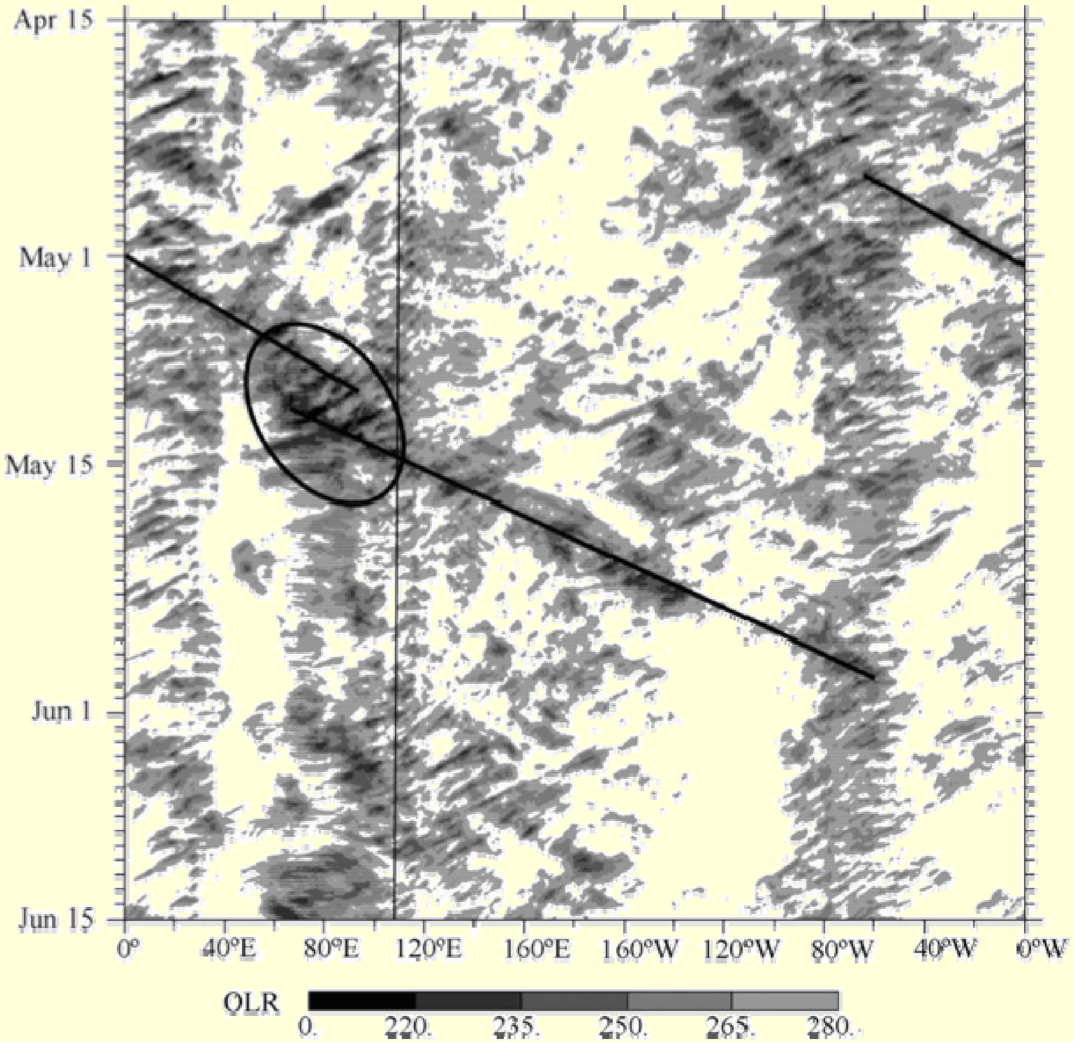


potentially good news for long predictability of tropical large scales

Mapes et al. 2008 JMSJ

Long predictability agrees with observational case persistence

K.H. Straub et al. / Dynamics of Atmospheres and Oceans 42 (2006) 216–238



1998 CLAUS Brightness Temperature 5ºS-5º N

The role of equatorial waves in the onset of the South China Sea summer monsoon and the demise of El Nino during 1998

Katherine H. Straub, George N. Kiladis, Paul E. Ciesielski

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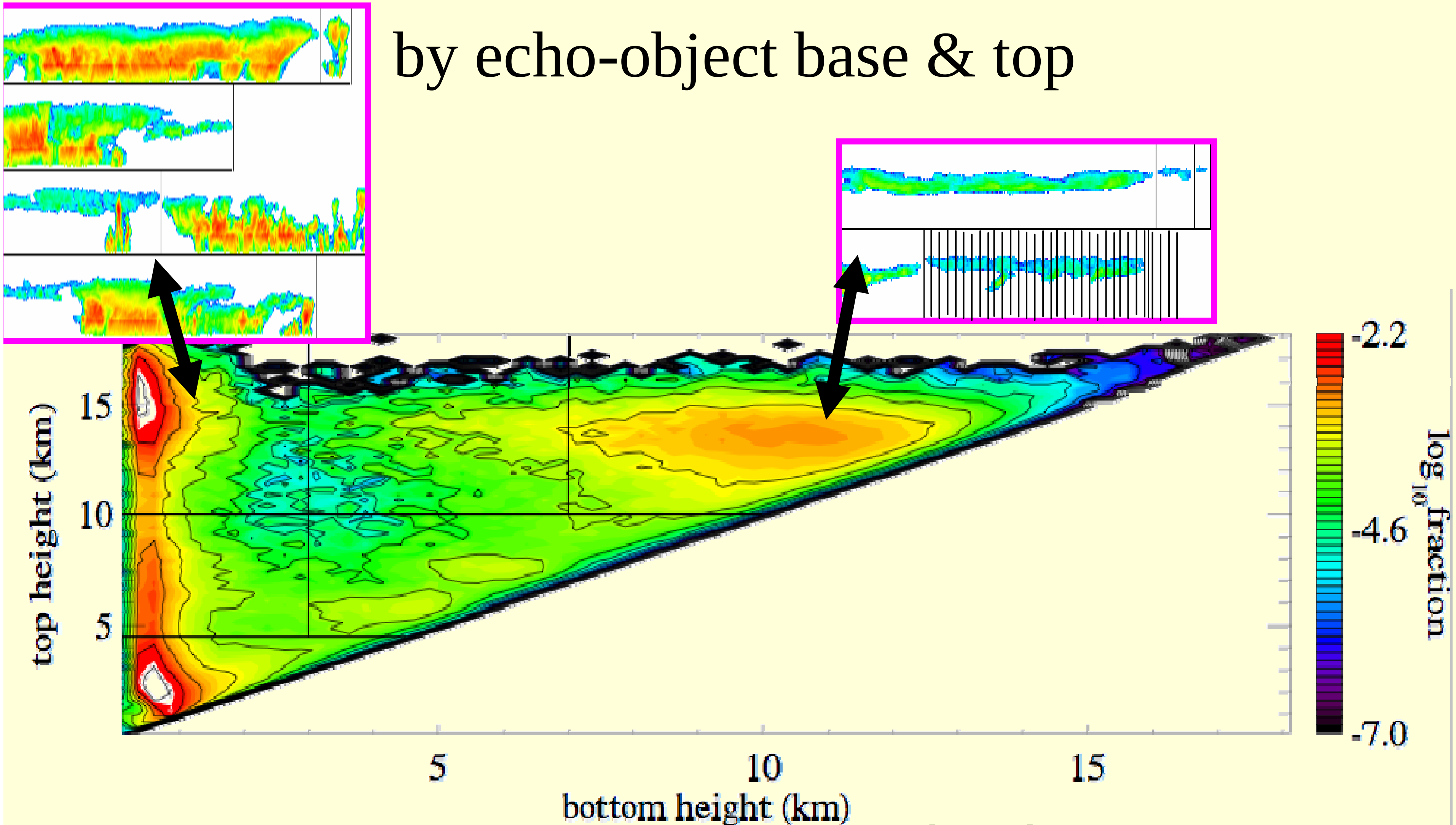
    - ‘Convection’: shallow -> deep -> stratiform rain

5. Meta-parameterization: an “ORG” scheme

Cloudsat climatology:

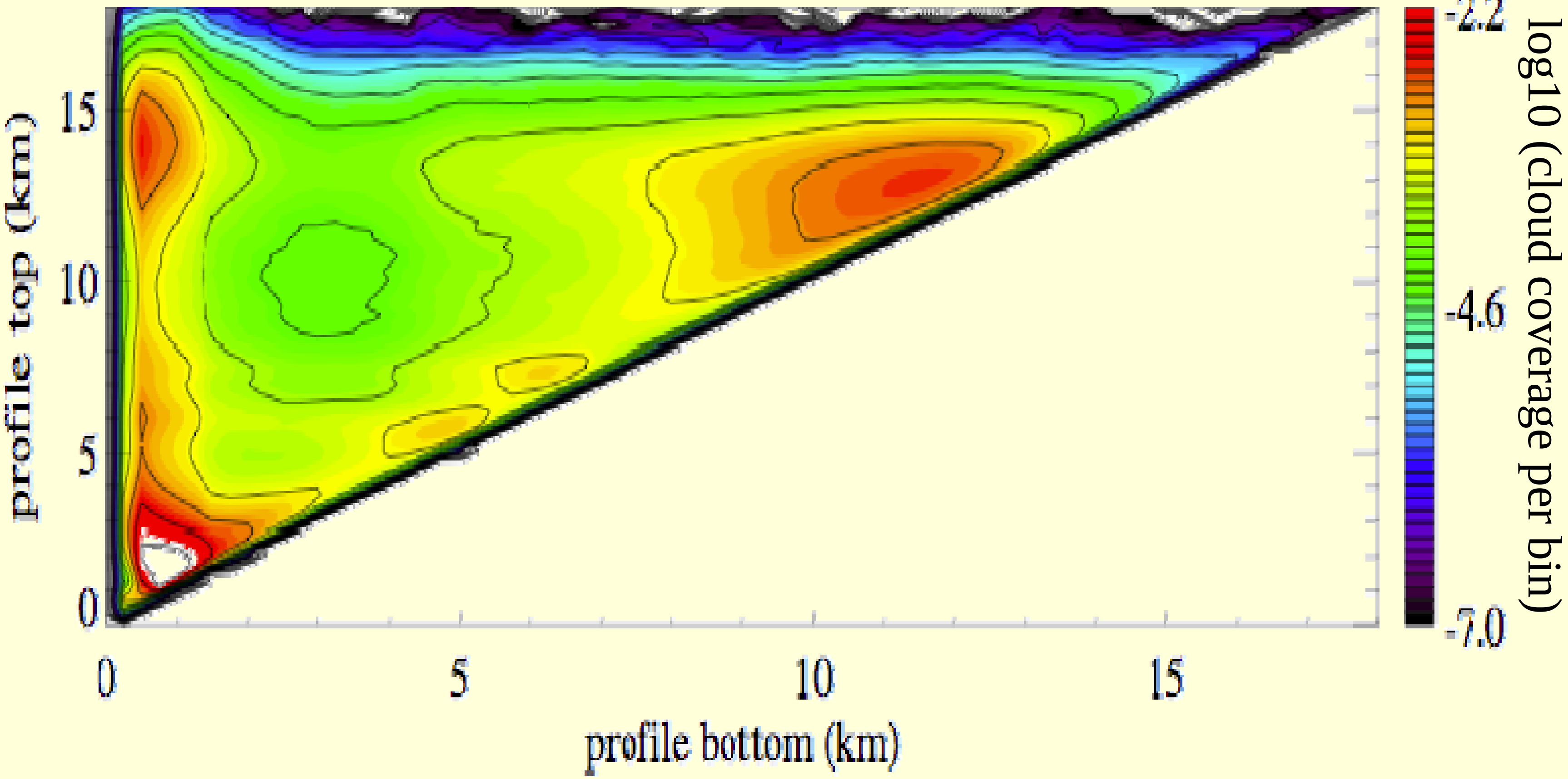
20N-20S annual mean cloud cover distribution by echo-object base & top



Riley and Mapes, in preparation

Tropical cloud cover

1 year Cloudsat cloud profiles, 20N-20S



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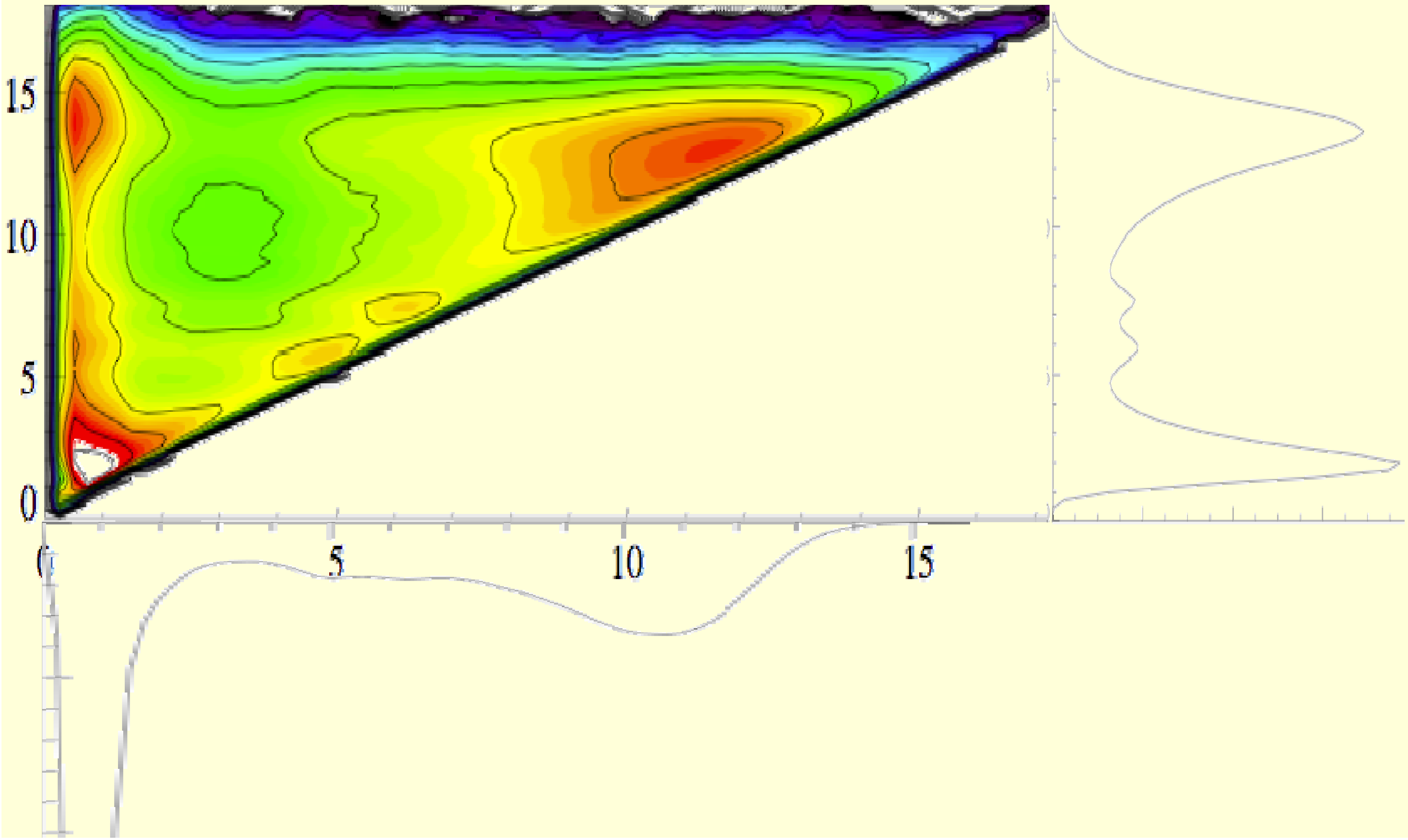

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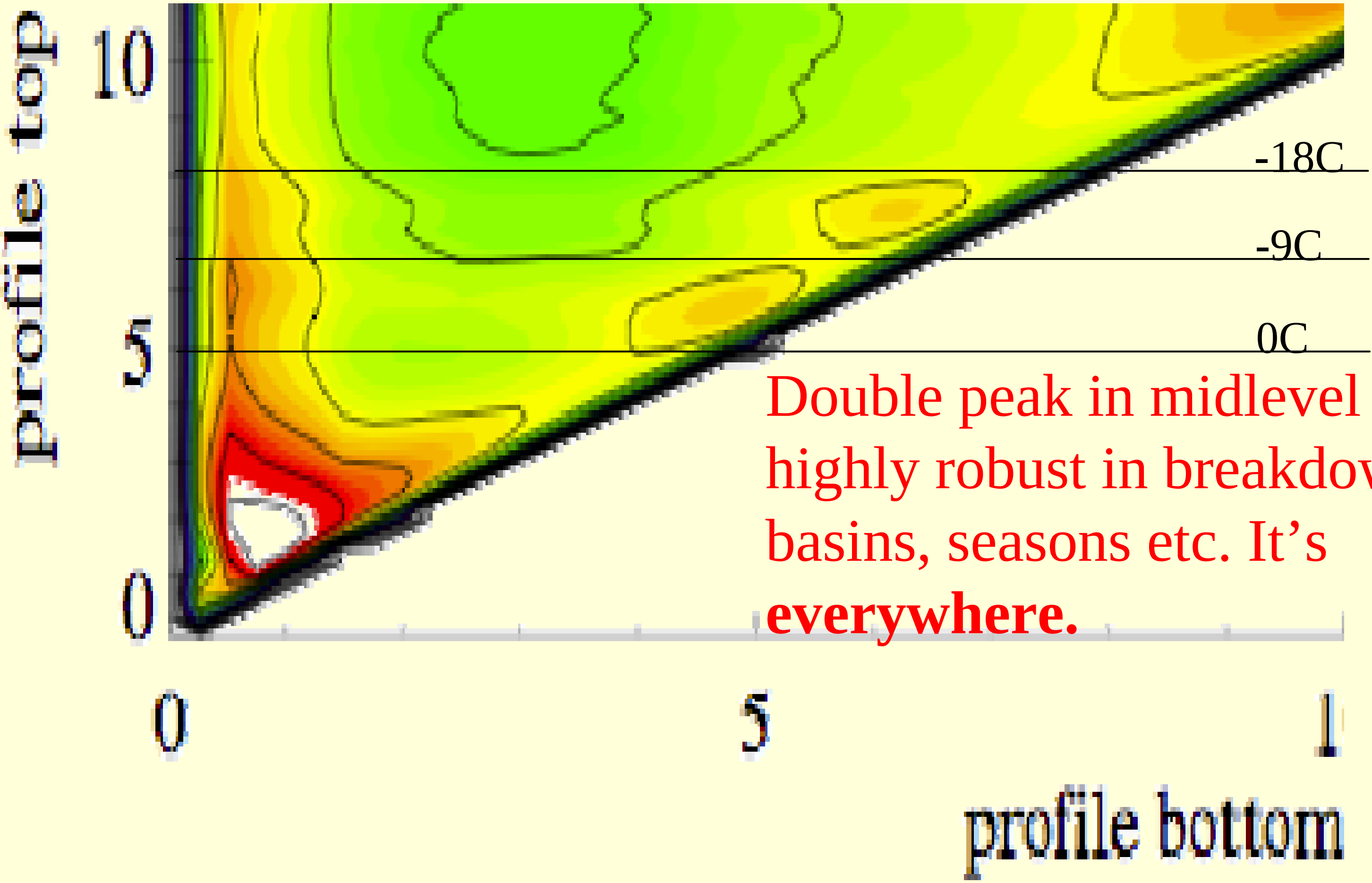
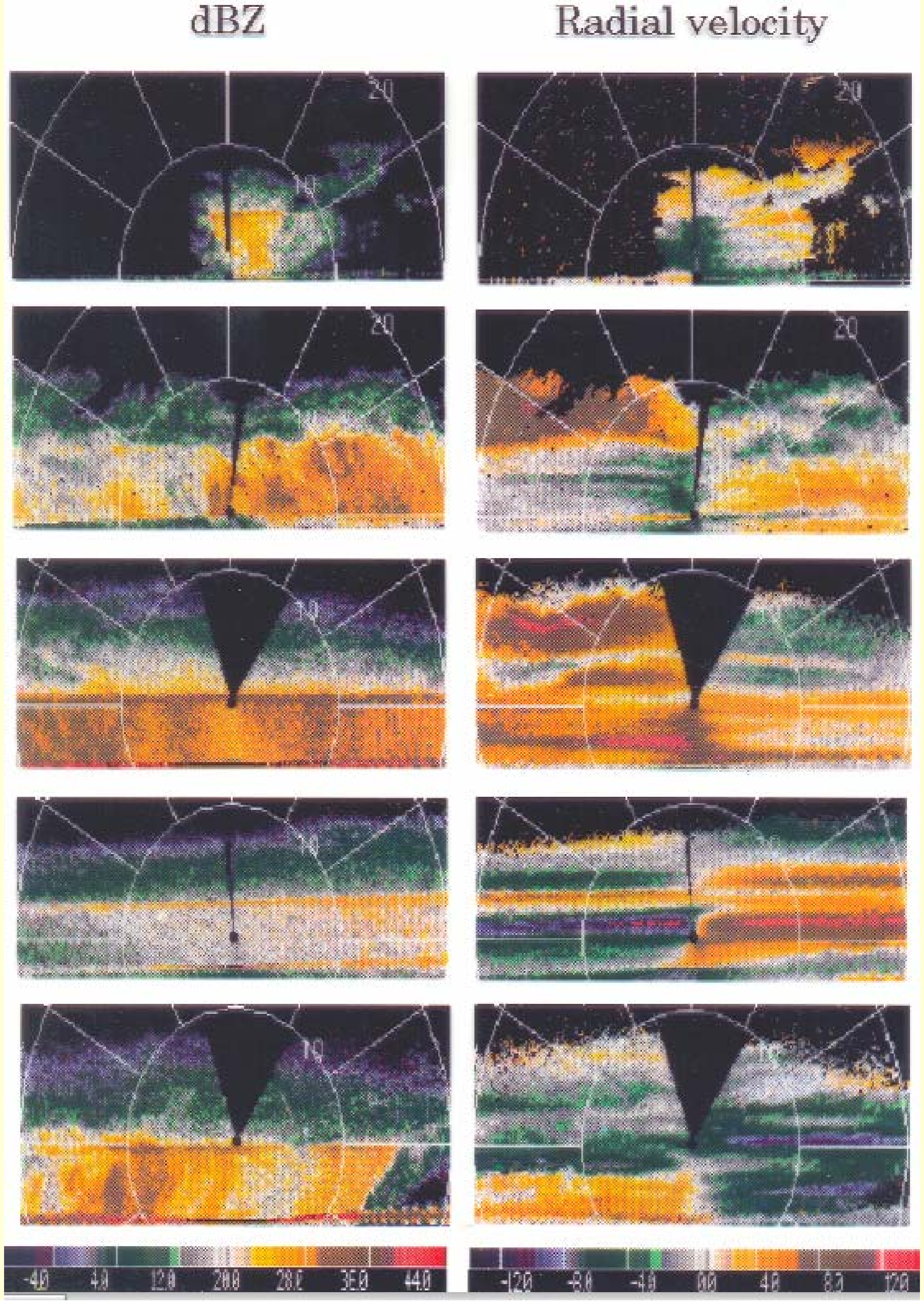


Double peak in midlevel clouds is highly robust in breakdowns by basins, seasons etc. It’s **everywhere.**

Airborne Doppler radar data:

Snow melts, whole troposphere shivers

(is wavelength set by melting layer thickness, or by a freeze-melt offset?)



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    - Congestus - stratiform complementary (‘mode 2’)
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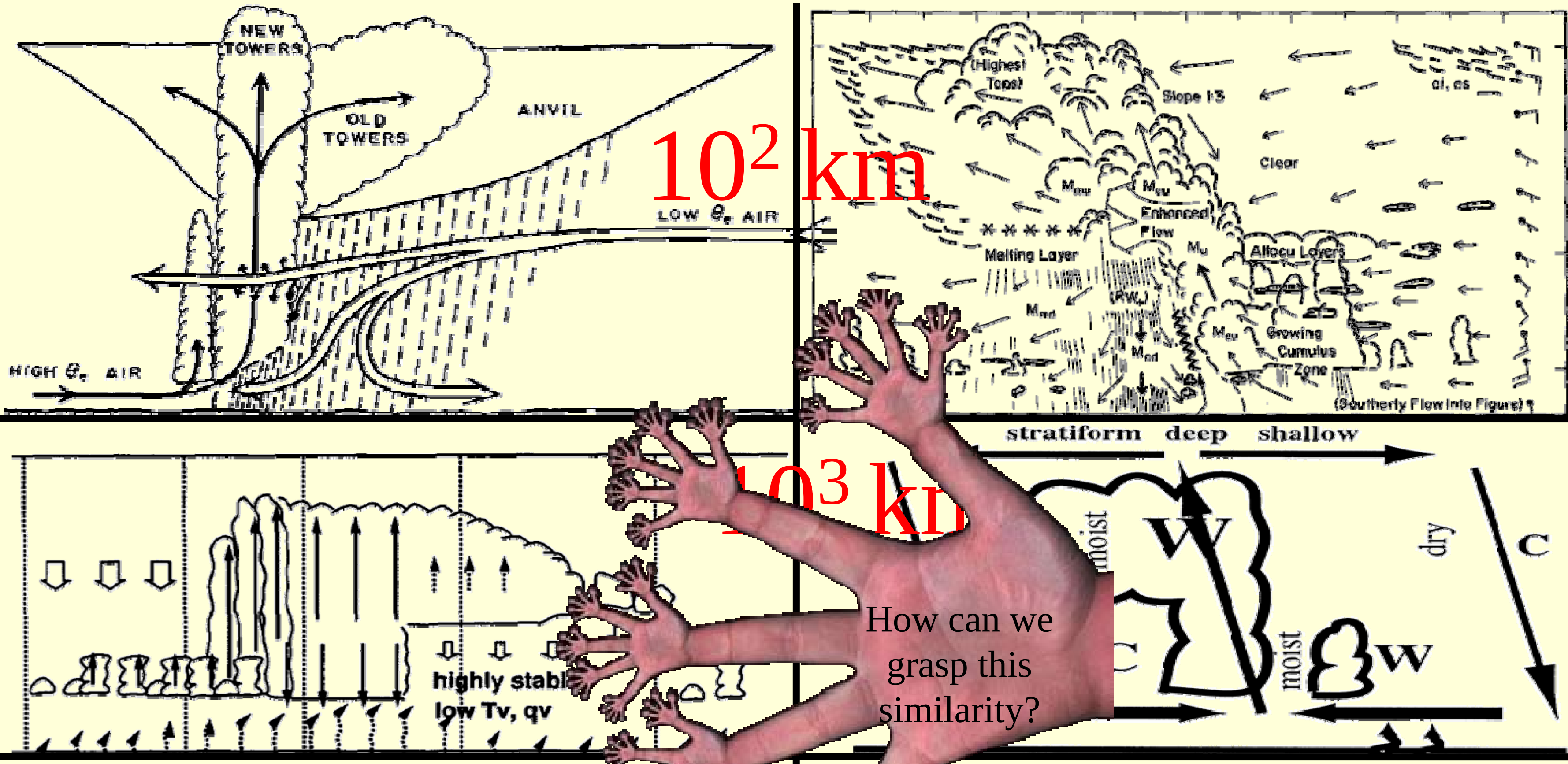
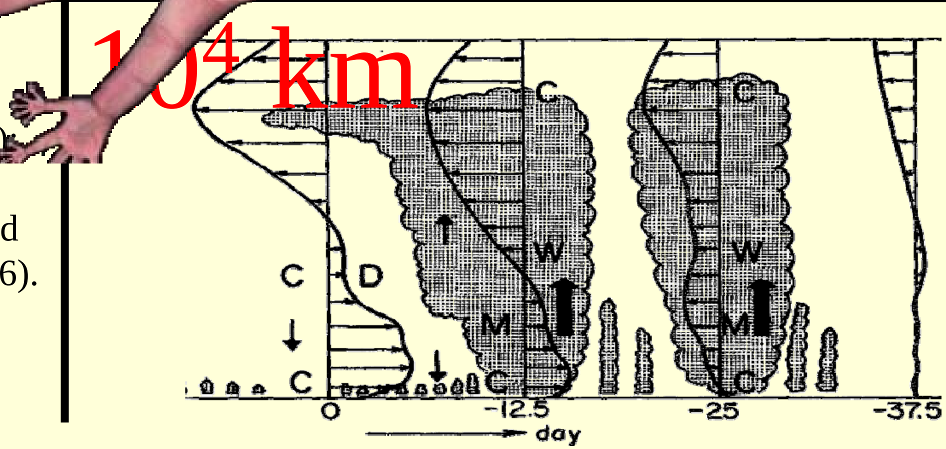


Figure 1. Conceptual models of:

a, b) mesoscale convective systems (Zipser 1969, 1981),
c) a two-day wave (Takayabu et al. 1996),
d) the moist Kelvin wave (Straub and Kiladis 2003), and
e) the Madden-Julian oscillation (Lin and Johnson 1996).

(Benedict & Randall is prettiest yet..)

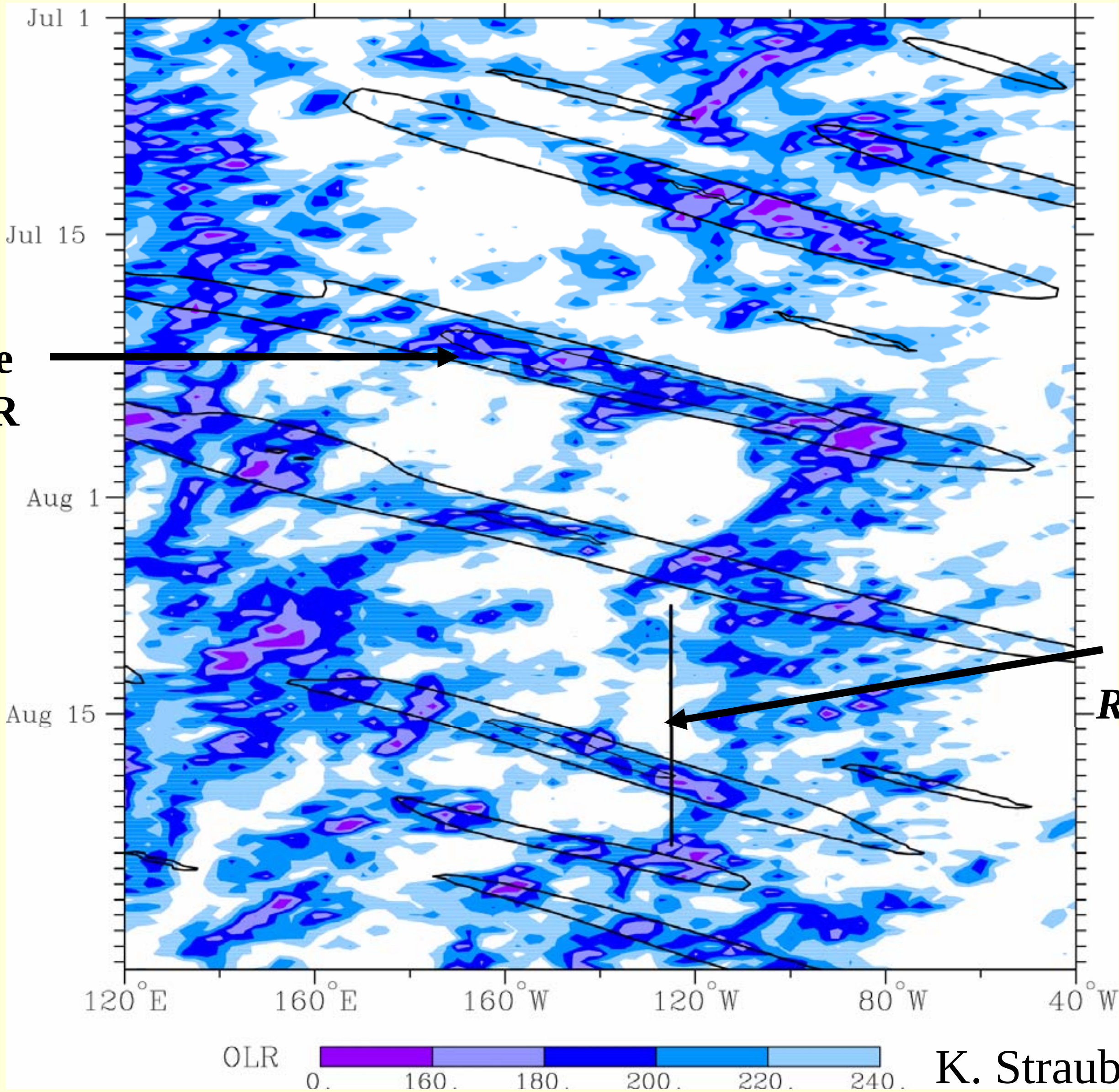


montage: Mapes et al. 2006 DAO

A Kelvin wave observed in detail (Straub and Kiladis 2005 JAS)

OLR (2.5N–15N), 1 July–31 August 1997

Contours: Kelvin wave filtered OLR

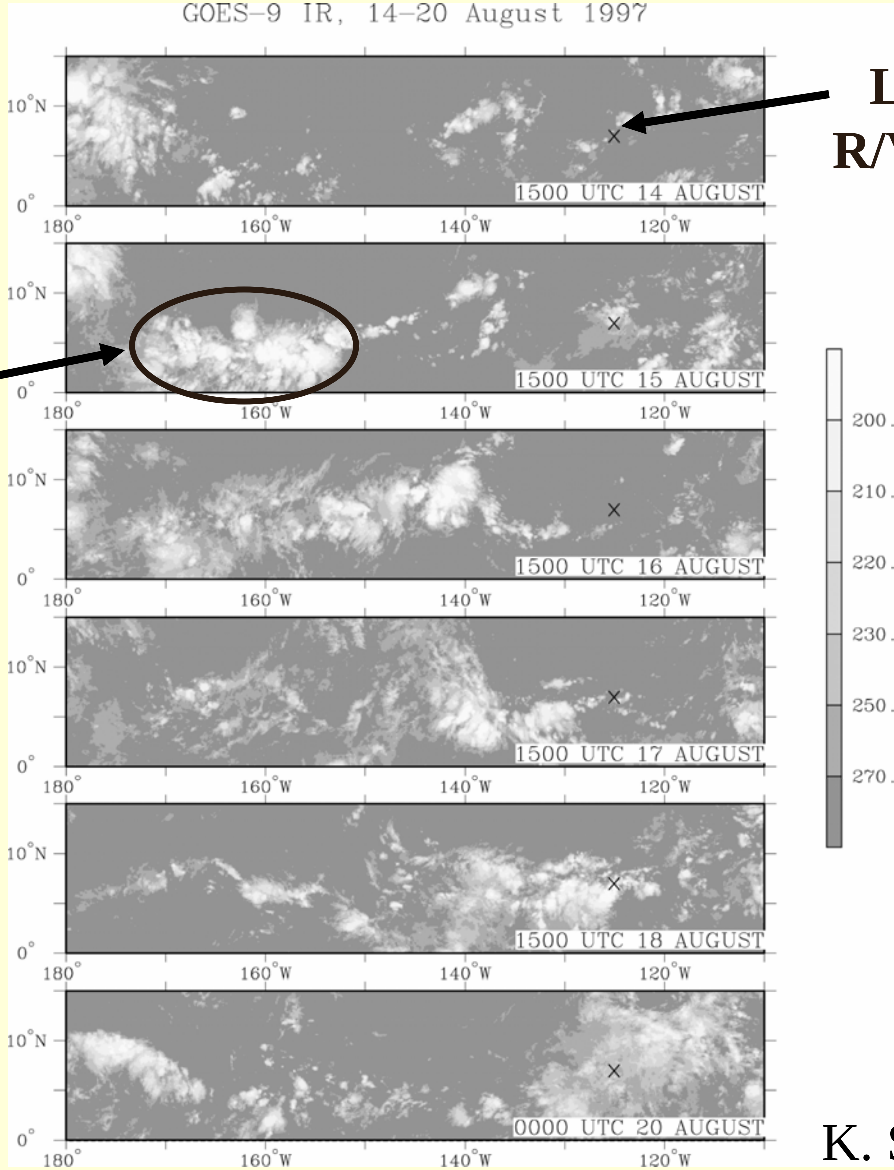


Location of NOAA ship *Ronald H. Brown* during TEPPS

K. Straub

TEPPS case study: *GOES–9* IR

6 IR images spanning 6 days during Kelvin wave passage



Location of R/V *Ronald H. Brown*

About 2000 km wide

K. Straub

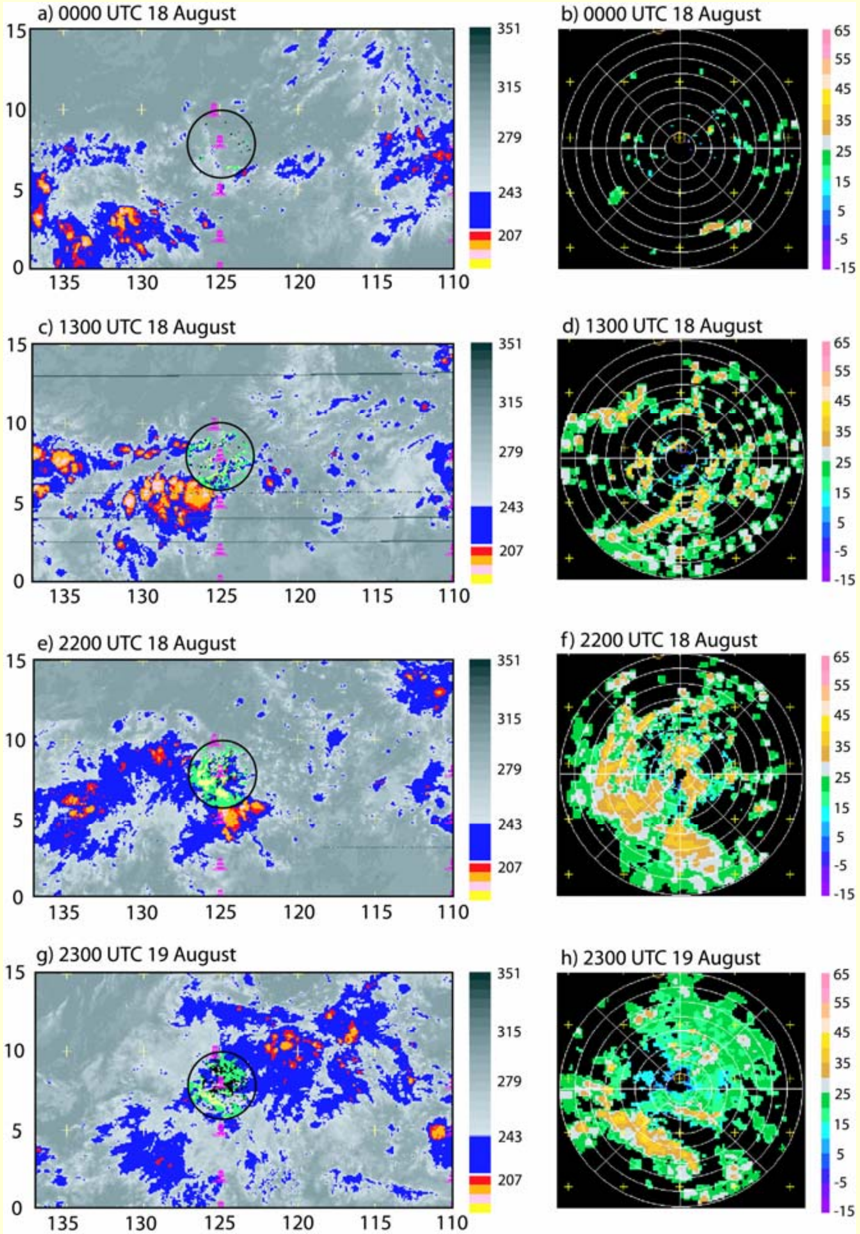
TEPPS case study: *GOES–9* IR and ship-based radar

00Z 18 August — **Shallow convection**

13Z 18 August — **Intensification; formation of convective lines**

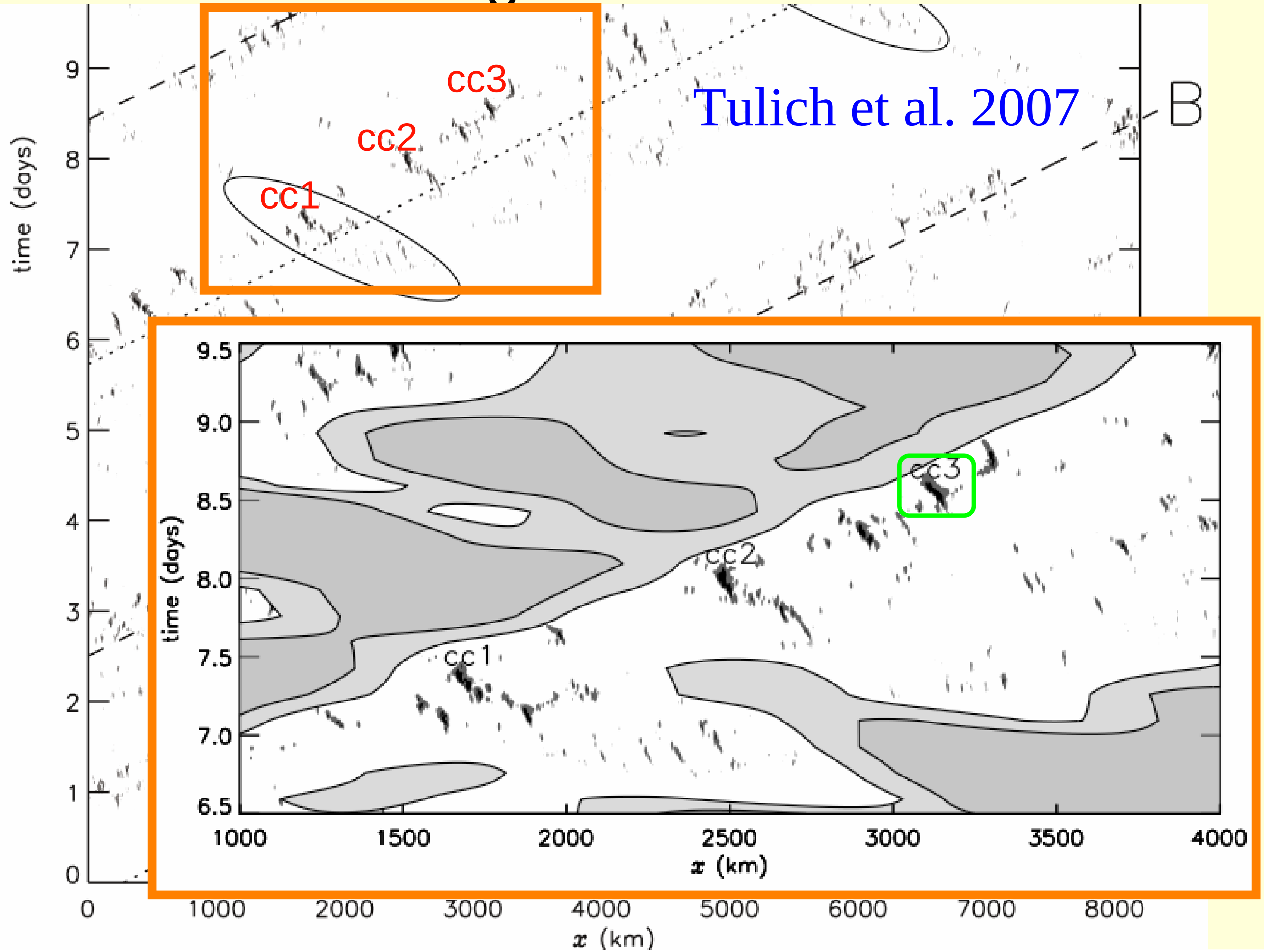
22Z 18 August — **Large systems with both convective and stratiform components**

23Z 19 August — **Primarily stratiform**



K. Straub

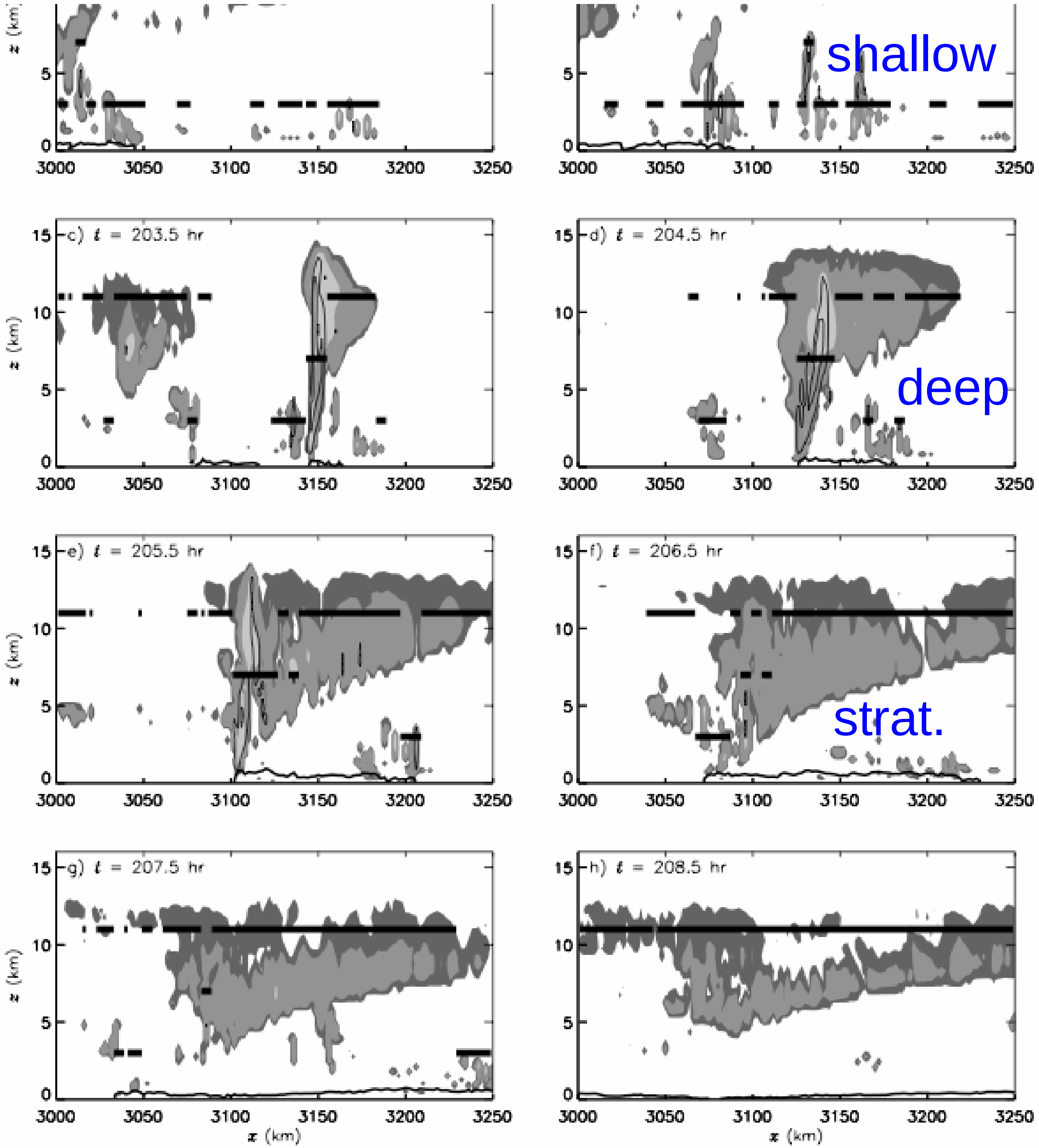
How scales fit together in 2D model wave



The life and death of cc3

a
multicellular
entity

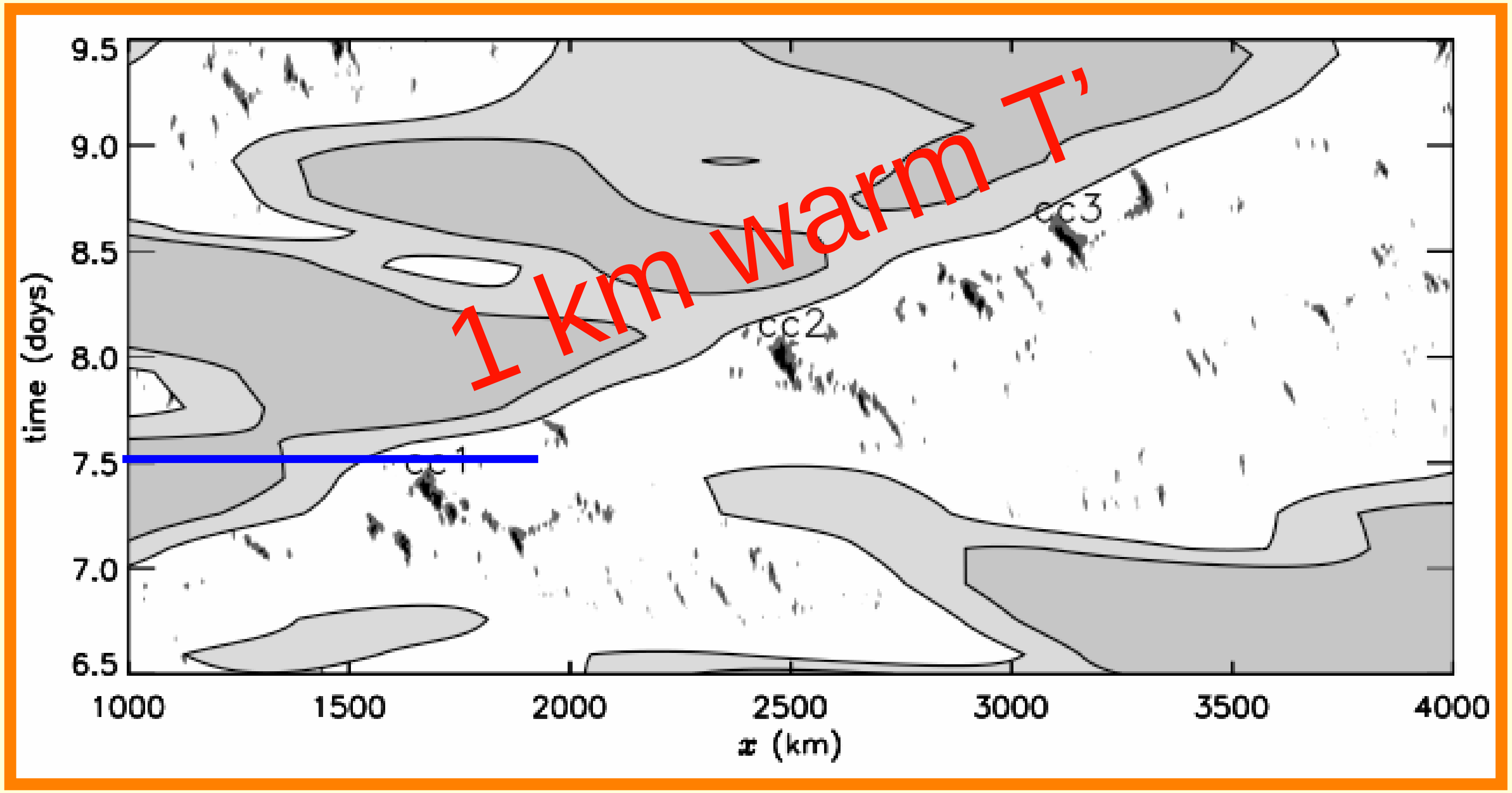
Tulich et al. 2007



Why do cc's die?

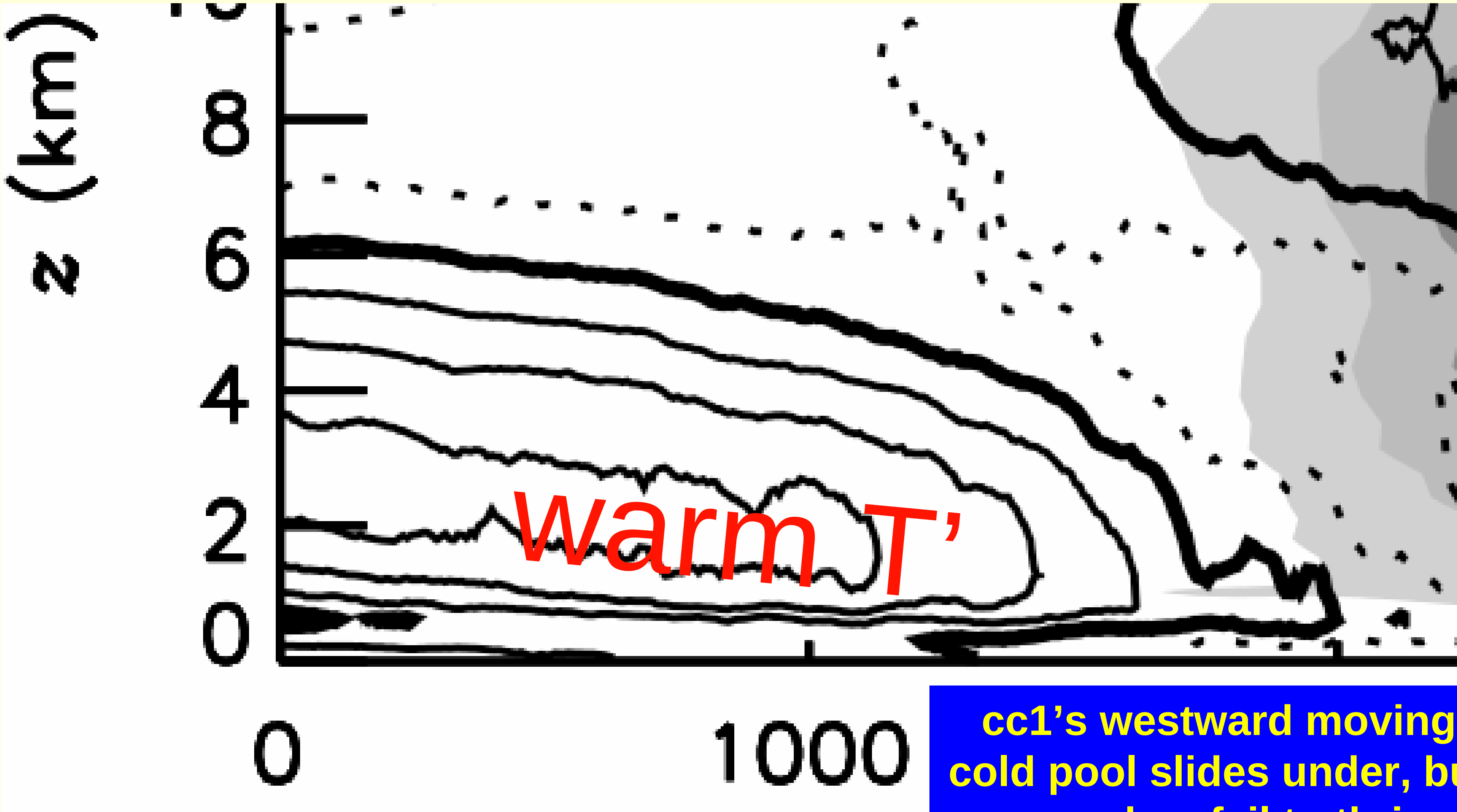
Why do new convective cells fail to form?

Consider cc1



Tulich et al. 2007

cell-killing warm wedge:
a downward displacement in LS wave



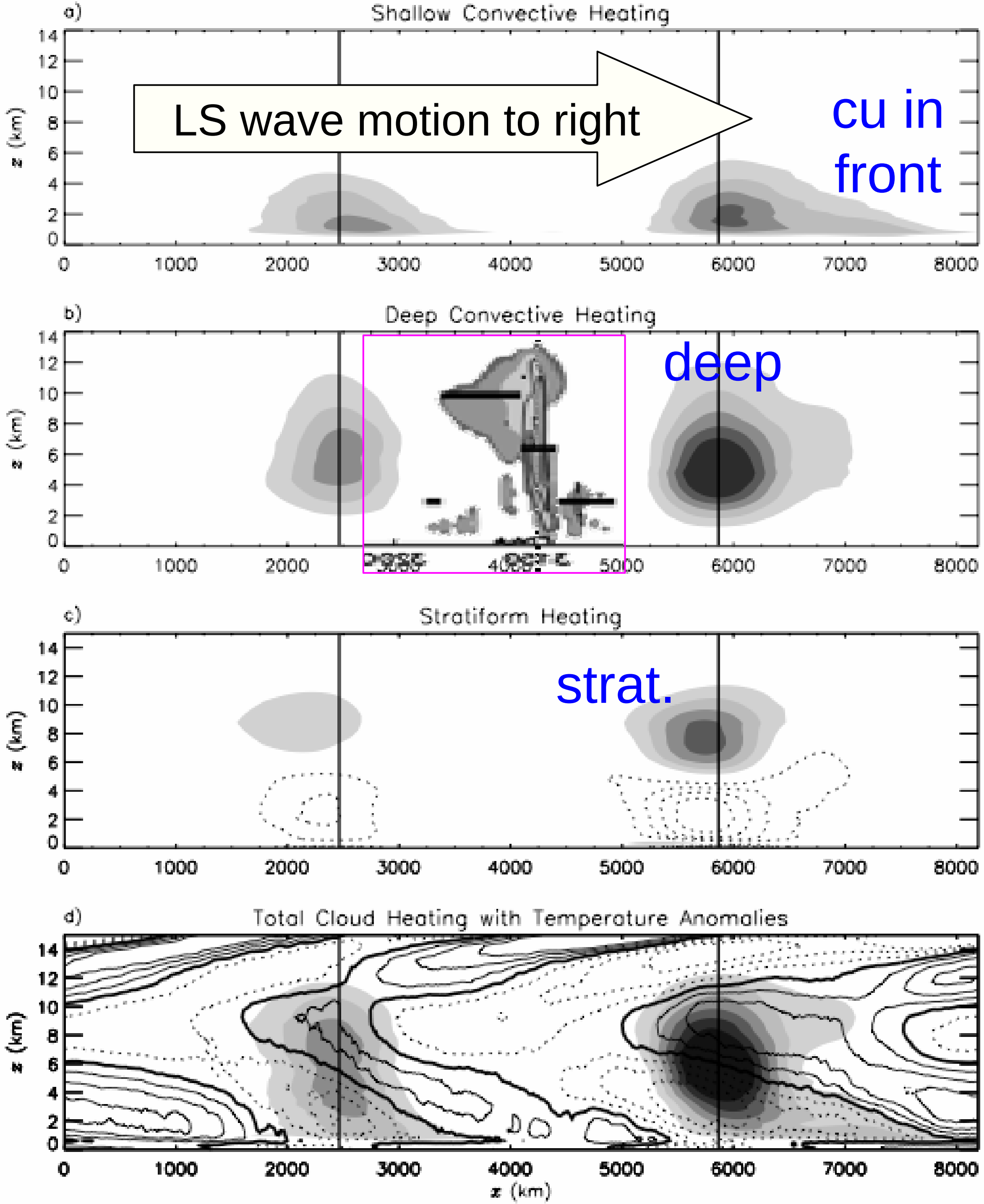
Tulich et al. 2007

cc1's westward moving cold pool slides under, but capped cu fail to thrive

What LS wave structure is the cell-killing 'wedge' part of?

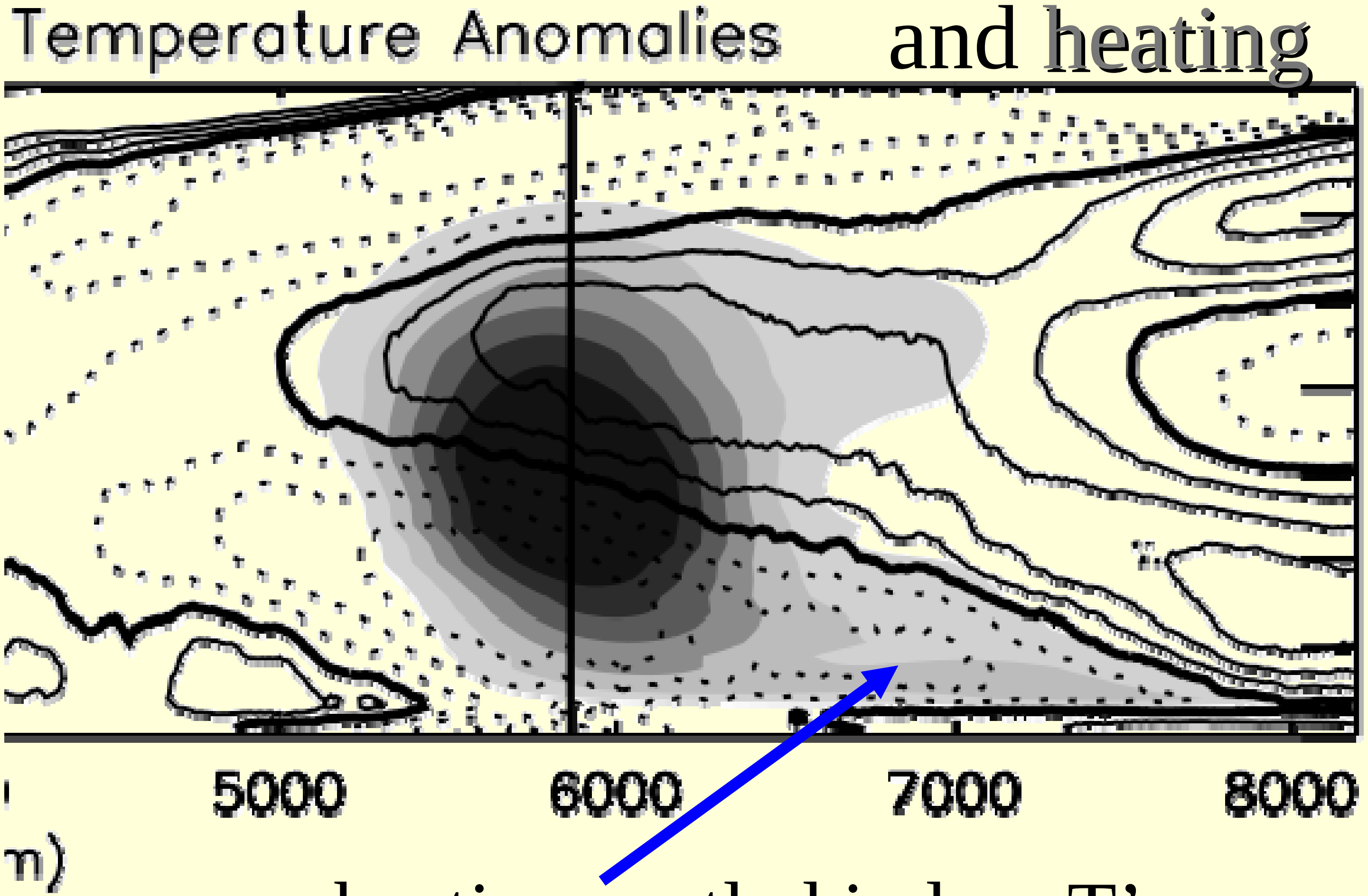
a larger (reversed) version of our friend cc3...

Tulich et al. 2007



Front edge: wave forces cu clouds

and heating



cu heating nestled in low T',

yet T' **keeps decreasing with time**

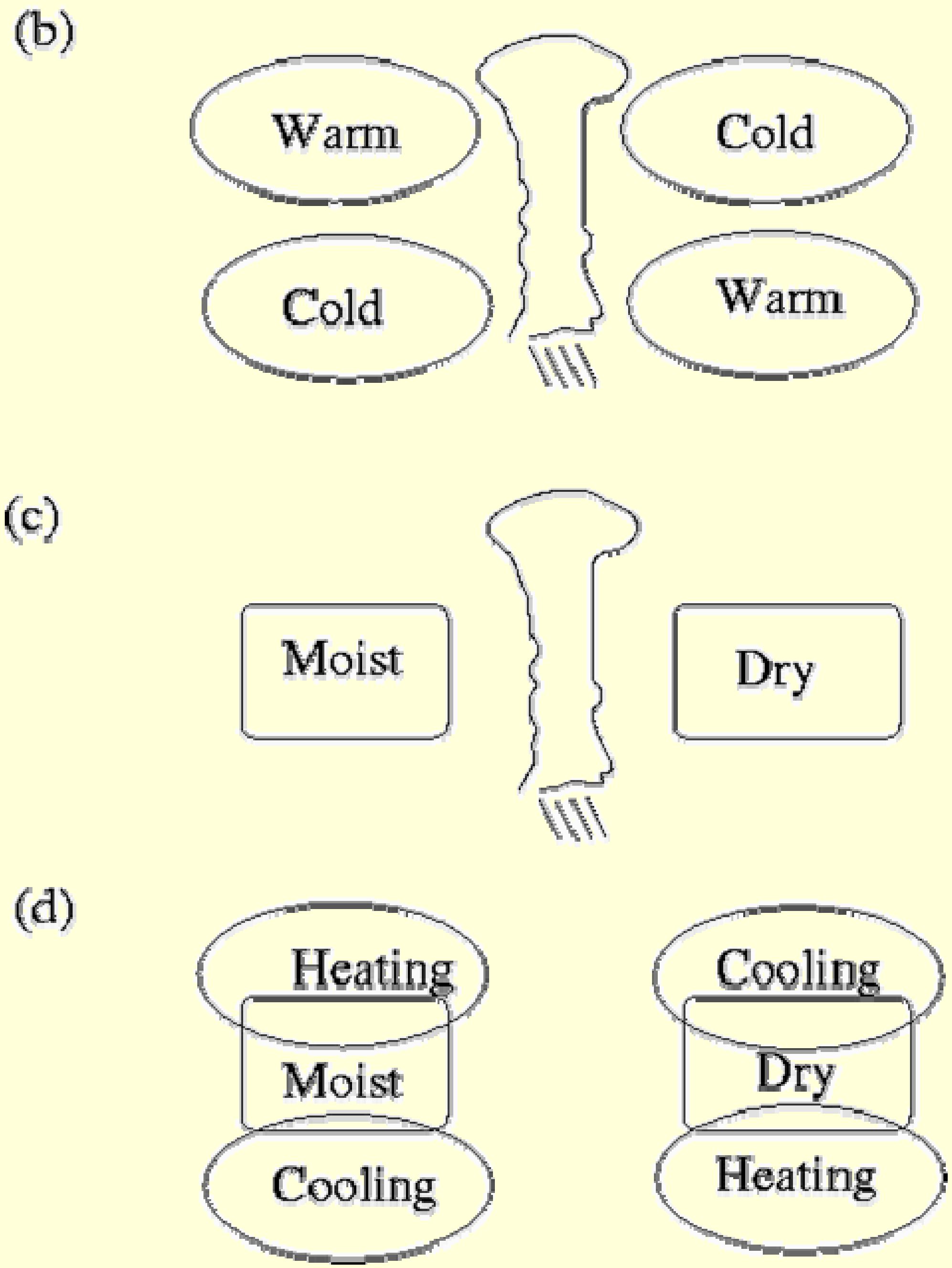
Tulich et al. 2007

Issue: relative roles of T vs. q in wave dynamics

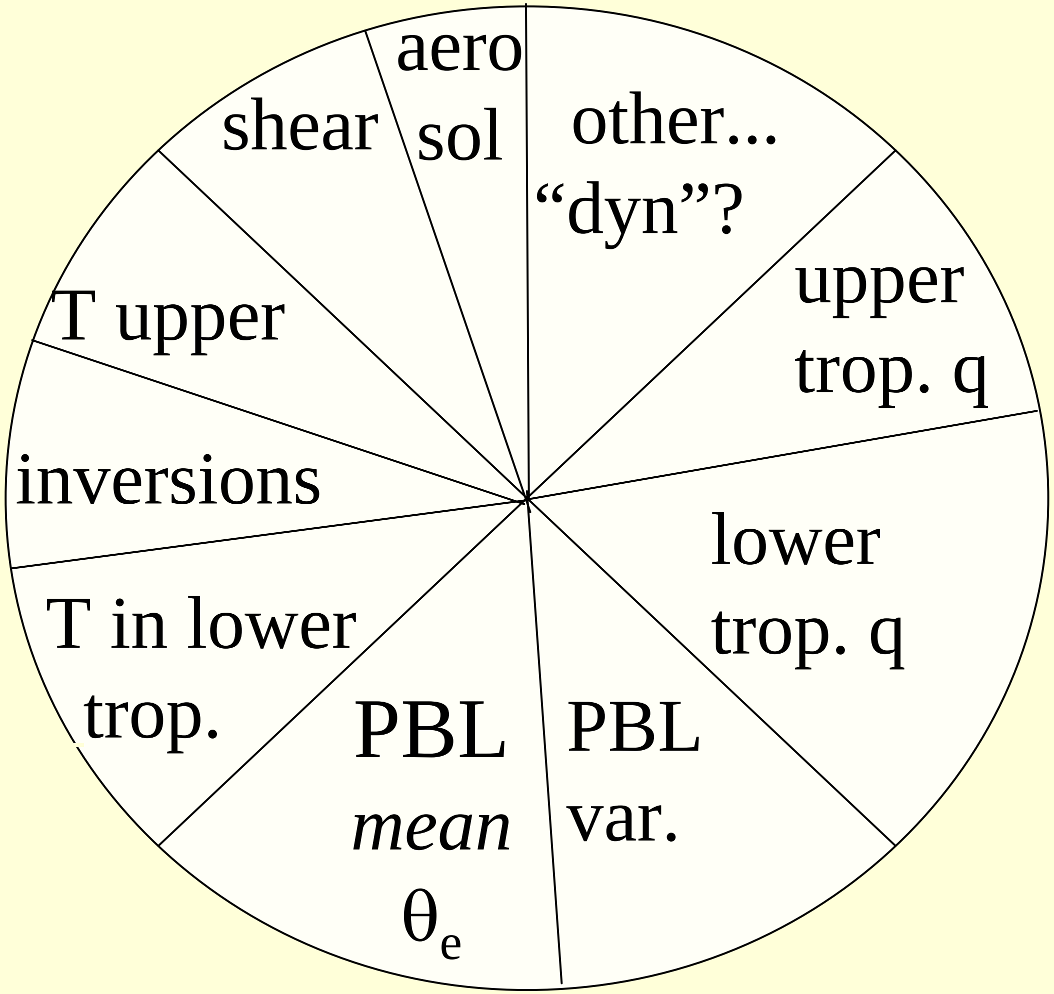
- **Journal of the Atmospheric Sciences**

A Moisture-Stratiform Instability for Convectively Coupled Waves

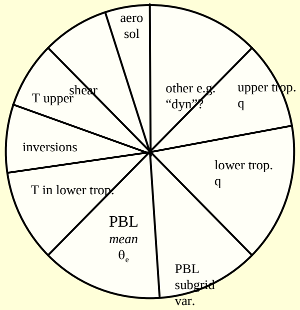
Zhiming Kuang 2008

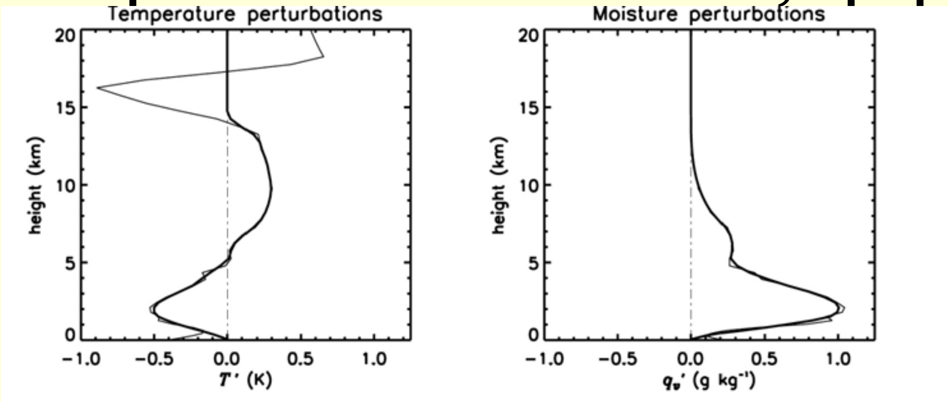


sensitivities of convection



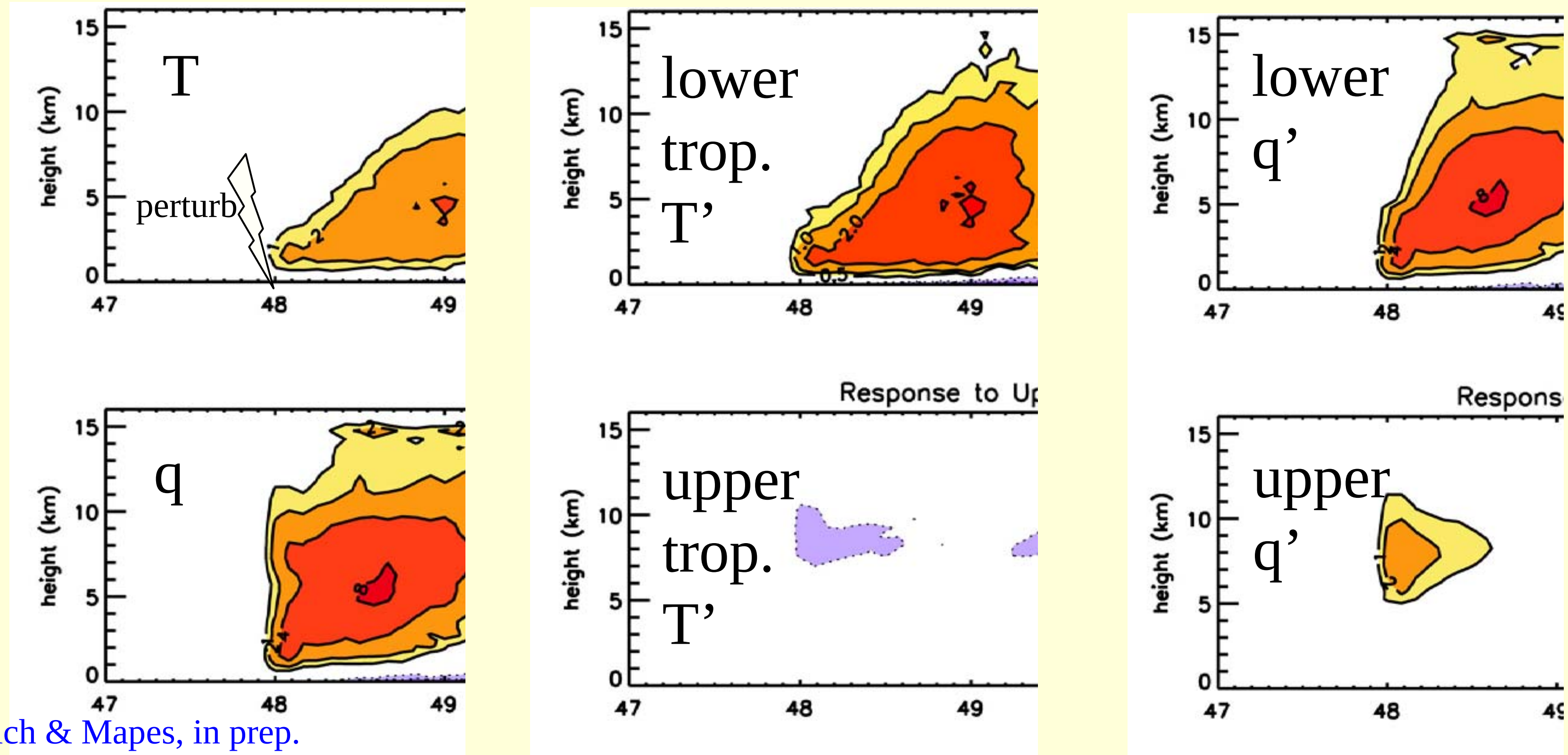
Probing the sensitivities of convection: CRM's Q1 response to sudden T', q' perturbations





probing signals nudged in 'instantly' and model responds

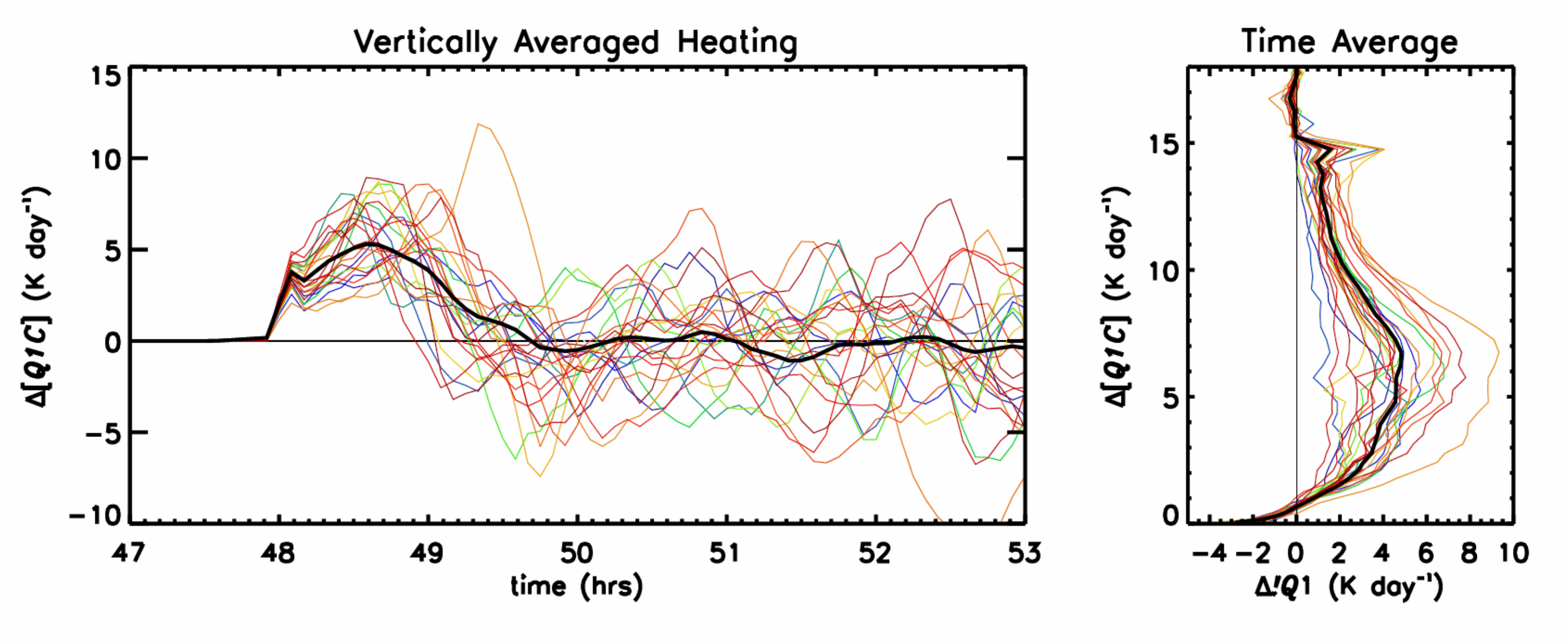
probes (**bold**) based on COARE sounding composites of T', q' just before rain (light curves)



Tulich & Mapes, in prep.

Thermodynamically probed CRM Results:

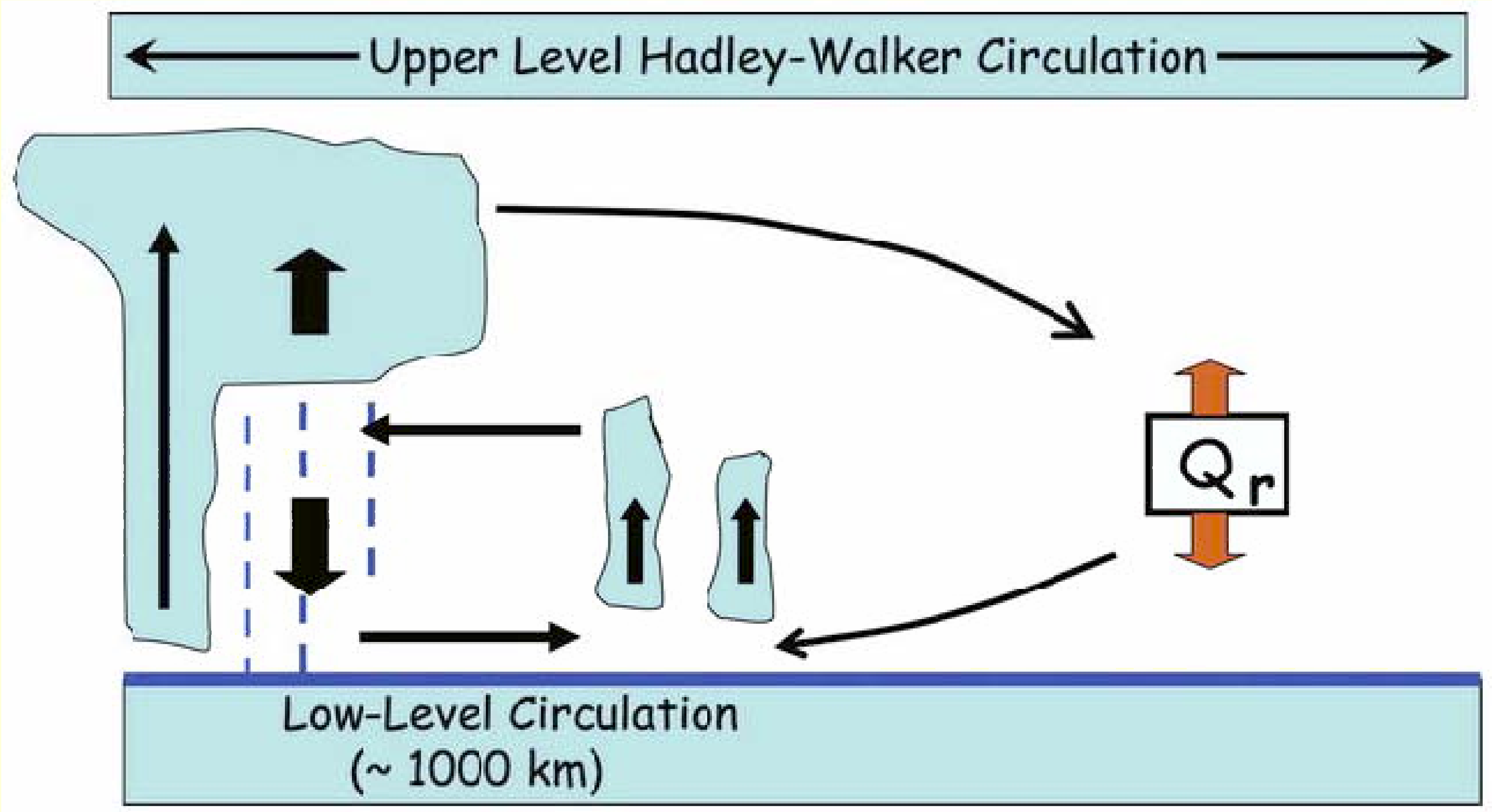
1. Low levels are more important than upper
2. About 60/40 sensitivity to q'/T' of obs. mag.
3. Response is highly ***linear***, but not very ***deterministic***, even with 128 x 128 km domain.



Tulich and Mapes, in prep.

1. Coupled wave-convection phenomena
   - Tropical: Kelvin and friends...MJO different?
   - Midlatitude: US summertime
2. Simulability with explicit convection models
3. Predictability inferred from persistence and
   - out to Medium Range sometimes...
4. Mechanisms and issues for parameterization
   - Ingredients: Tropical cloud types
   - 'Convection': shallow -> deep -> stratiform rain
   - Shallow & stratiform: complementary diabatic forcings of tropospheric vertical dipole mode

Stratiform & congestus complementary



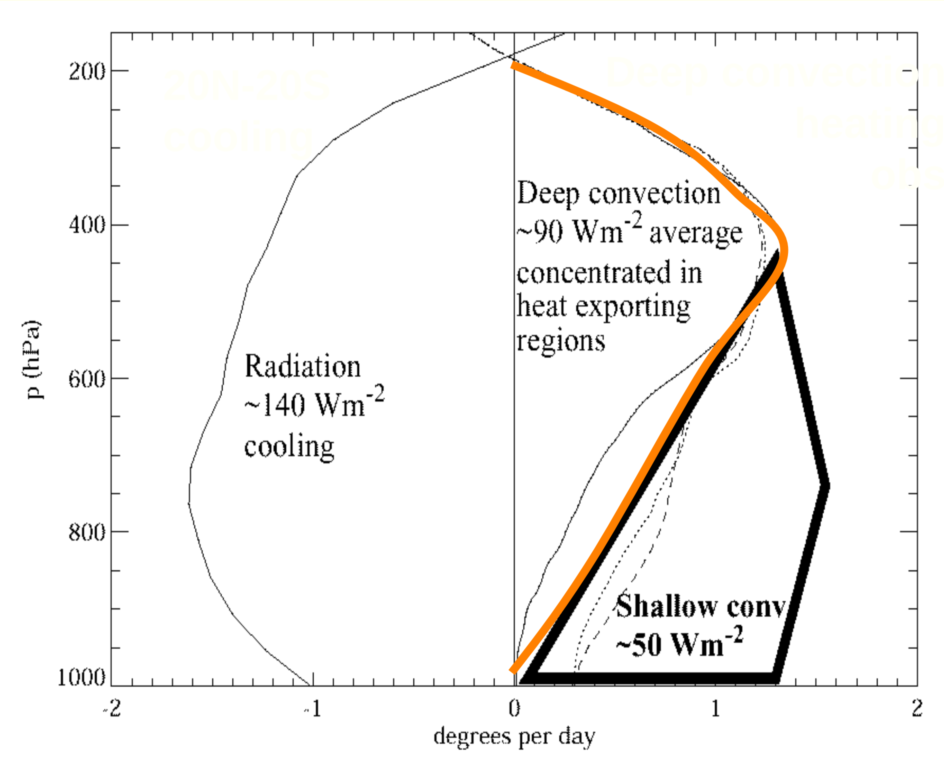
Folkins et al. 2008 JAS

A low level circulation in the tropics

No fundamental source -> GCMs can miss it

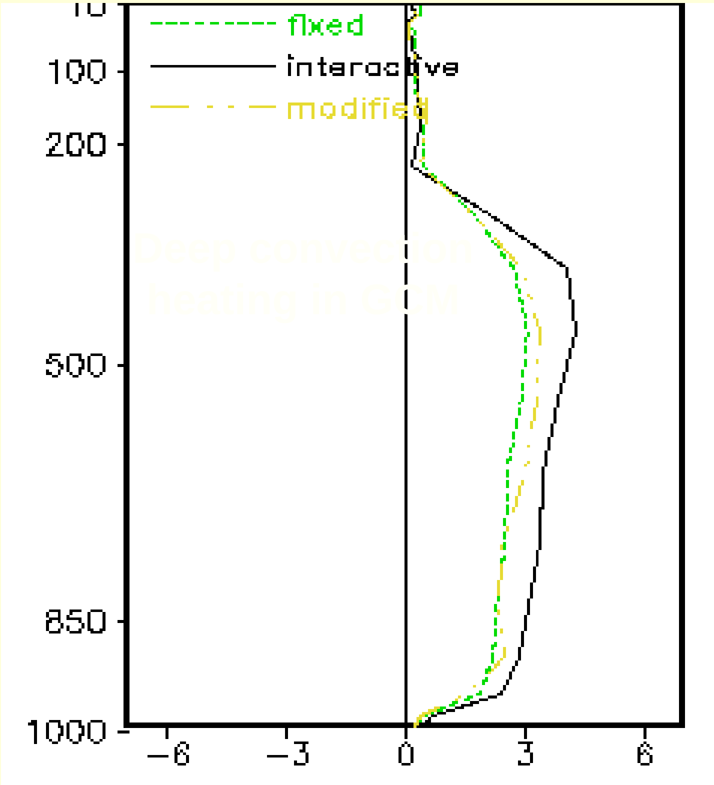
Lack of stratiform physics, or of cumulus shower physics?

Earth tropics



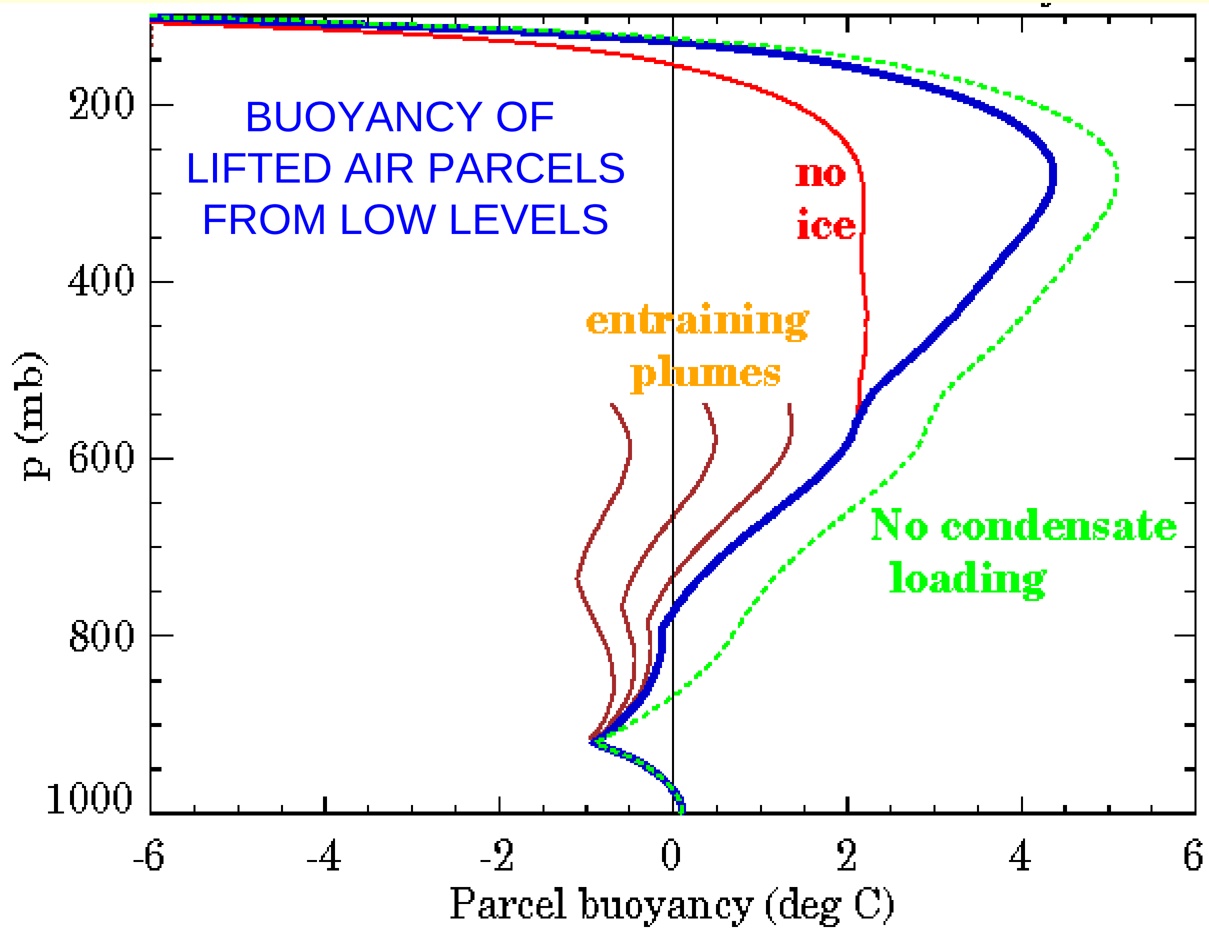
Mapes 2000

GCM rainy area heating



Lee Kang Mapes 2001

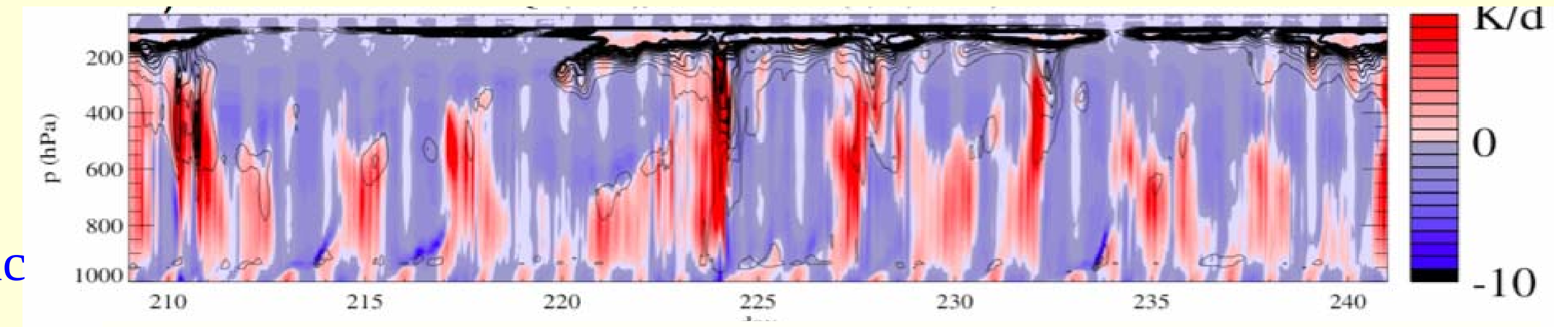
Hard to get entraining plumes (with constant ε) to be buoyant enough to ascend, but then to stop halfway, in a realistic sounding



Need entrainment ***tricks***!

(as ECMWF has discovered...Bechtold et al. 2008 QJ)

Degree of excitation of vertical dipole mode by diabatic heating Q1 varies a lot from GCM to GCM

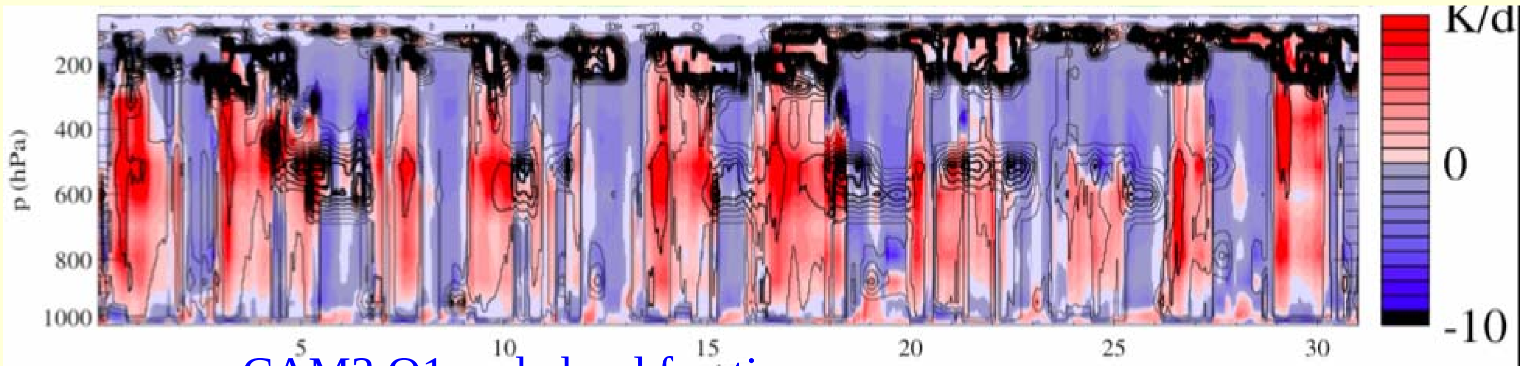


KWAJEX OBS-forced CRM not identical months- notice texture only)

as does tropical variability simulation quality...

coincidence?

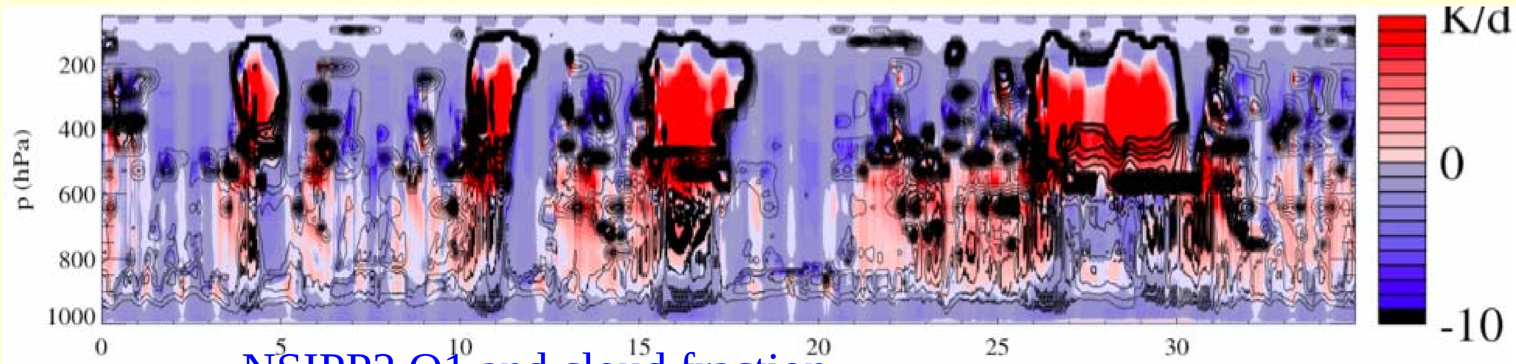
more work needed



CAM3 Q1 and cloud fraction

Mapes et al. in press J. Climate

Virtual field campaigns...



NSIPP2 Q1 and cloud fraction

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    - out to Medium Range sometimes...
4. Mechanisms and issues
    - Ingredients: shallow & deep convxn; stratiform rain
    - Relationships
5. Parameterization improvement activities
    - SCM w/ paramzd LSD GCSS WG4 activity in prep.
    - Meta-parameterization: an "ORG" scheme

A concrete GCSS proposal:

Study interaction of convection with ***one large scale at a time***

- large scale dynamics ***parameterized***
  - (**interactive**, not prescribed as **forcing**)

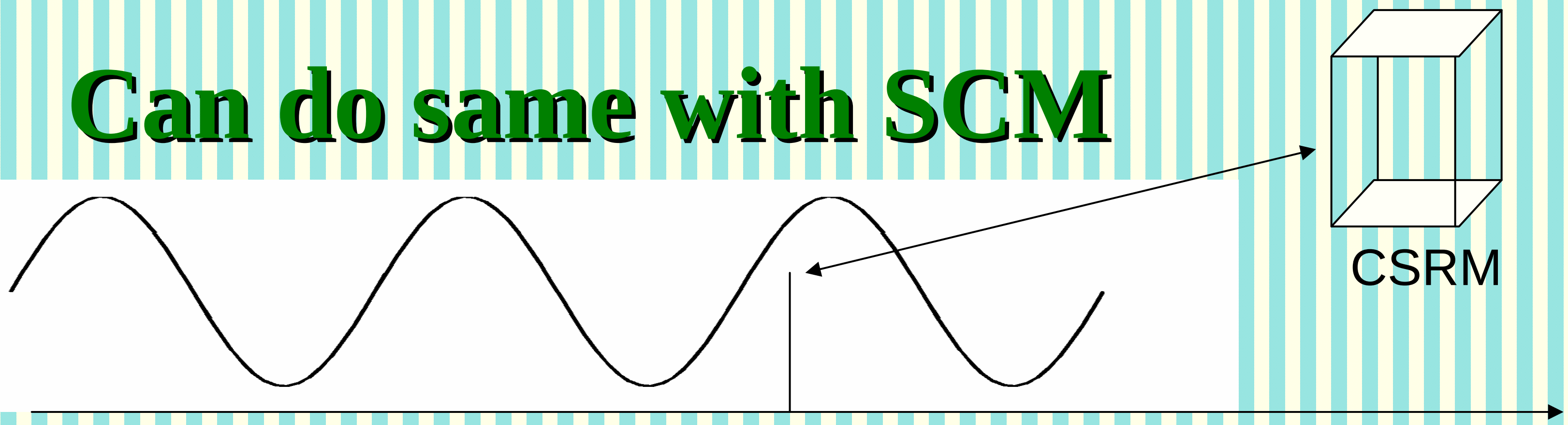
- Kuang (2008 JAS): a clean approach
  - interaction of convecting column physics with linear plane gravity wave dynamics of ***one specified horizontal wavelength***
    - **(c.f. Brown and Bretherton 1996)**

Zhiming Kuang's slide (with his interested permission)

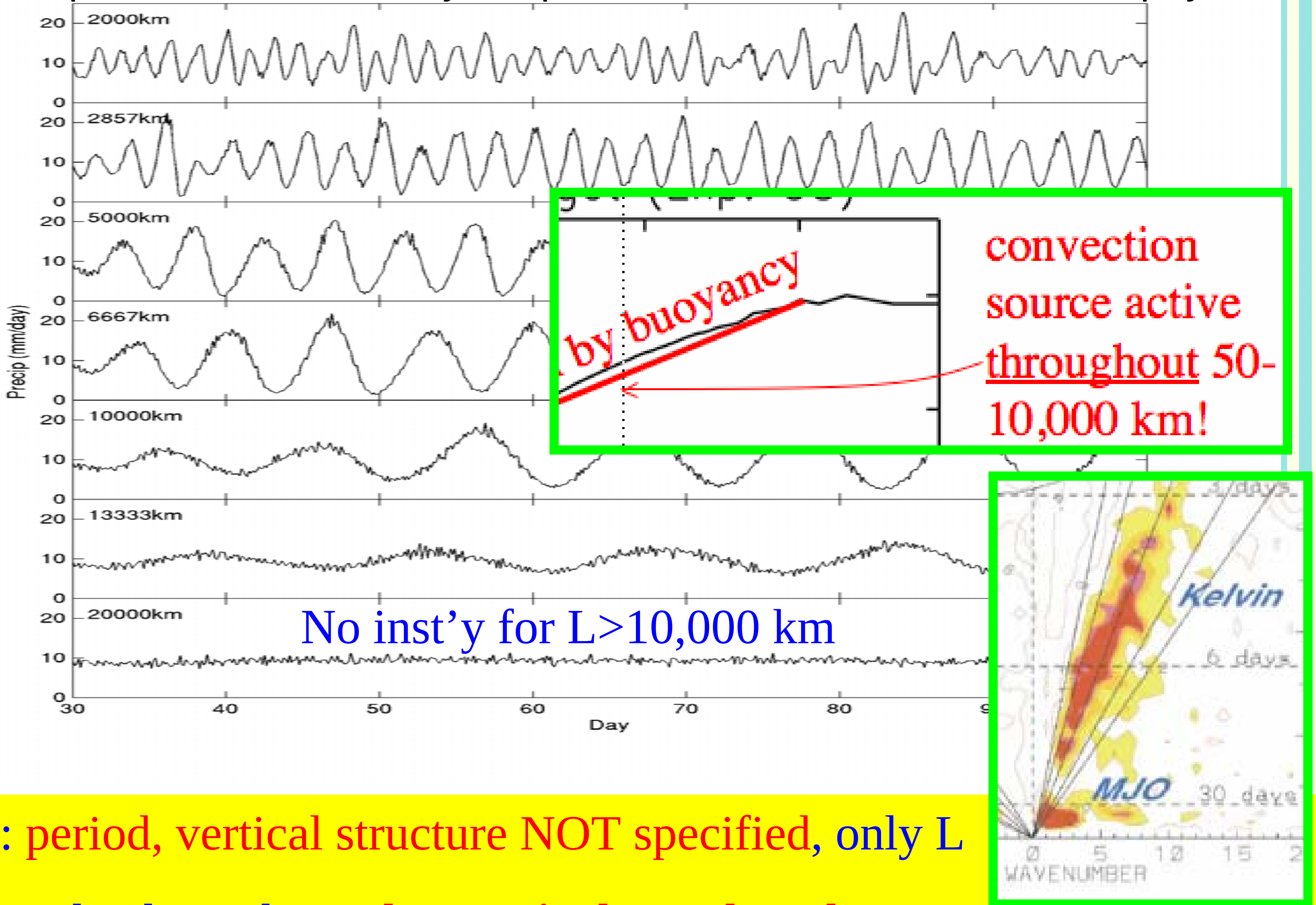
Our approach

- Coupling between convection and 2D linear gravity waves
- One horizontal wavenumber at a time
- CSRM as a vertical line in the wave

Can do same with SCM



Development of convectively coupled waves w/ CSRM as column phys.



- Note: period, vertical structure NOT specified, only L
  - results depend on ***what vertical wavelengths convection chooses to couple to*** (in this CRM, the vertical dipole mode w/ ~15 m/s speed)

1. Coupled wave-convection phenomena
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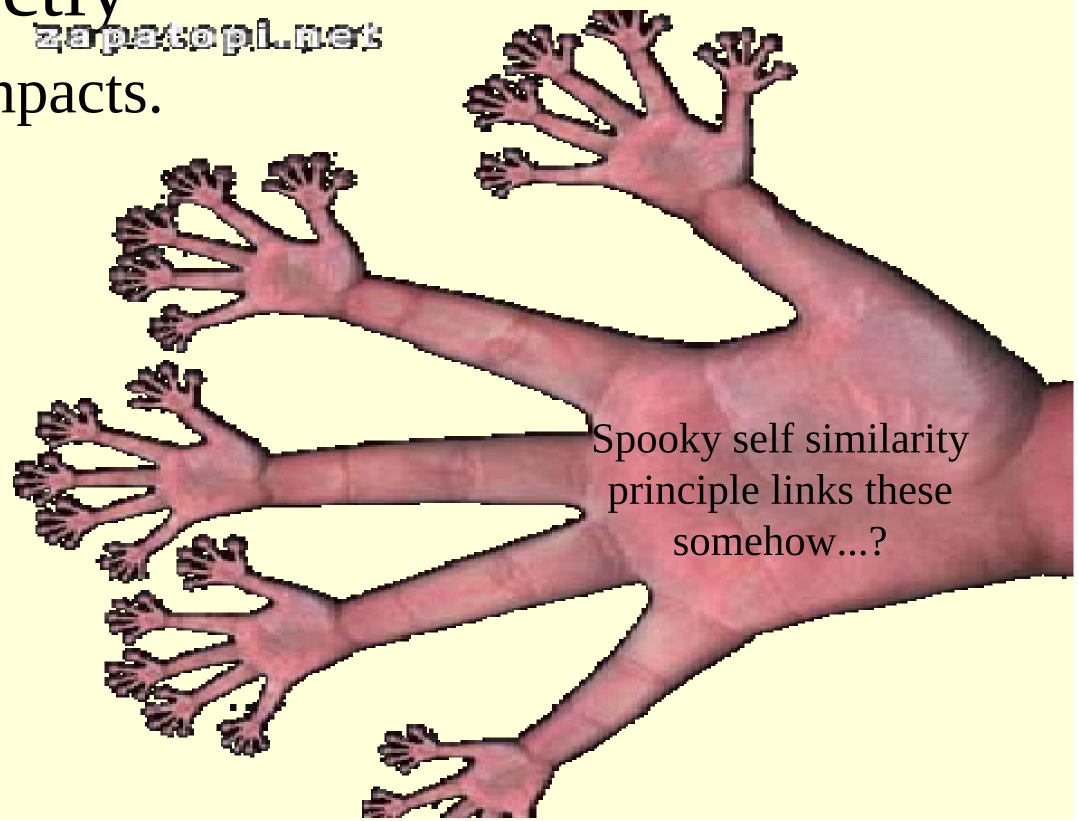
4. Mechanisms and issues
   - Ingredients: shallow & deep convxn; stratiform rain
   - Relationships
5. Modeling activities
   - SCM w/ paramzd LSD: GCSS activity in prep.
   - Meta-parameterization: “ORG” scheme (in CAM)

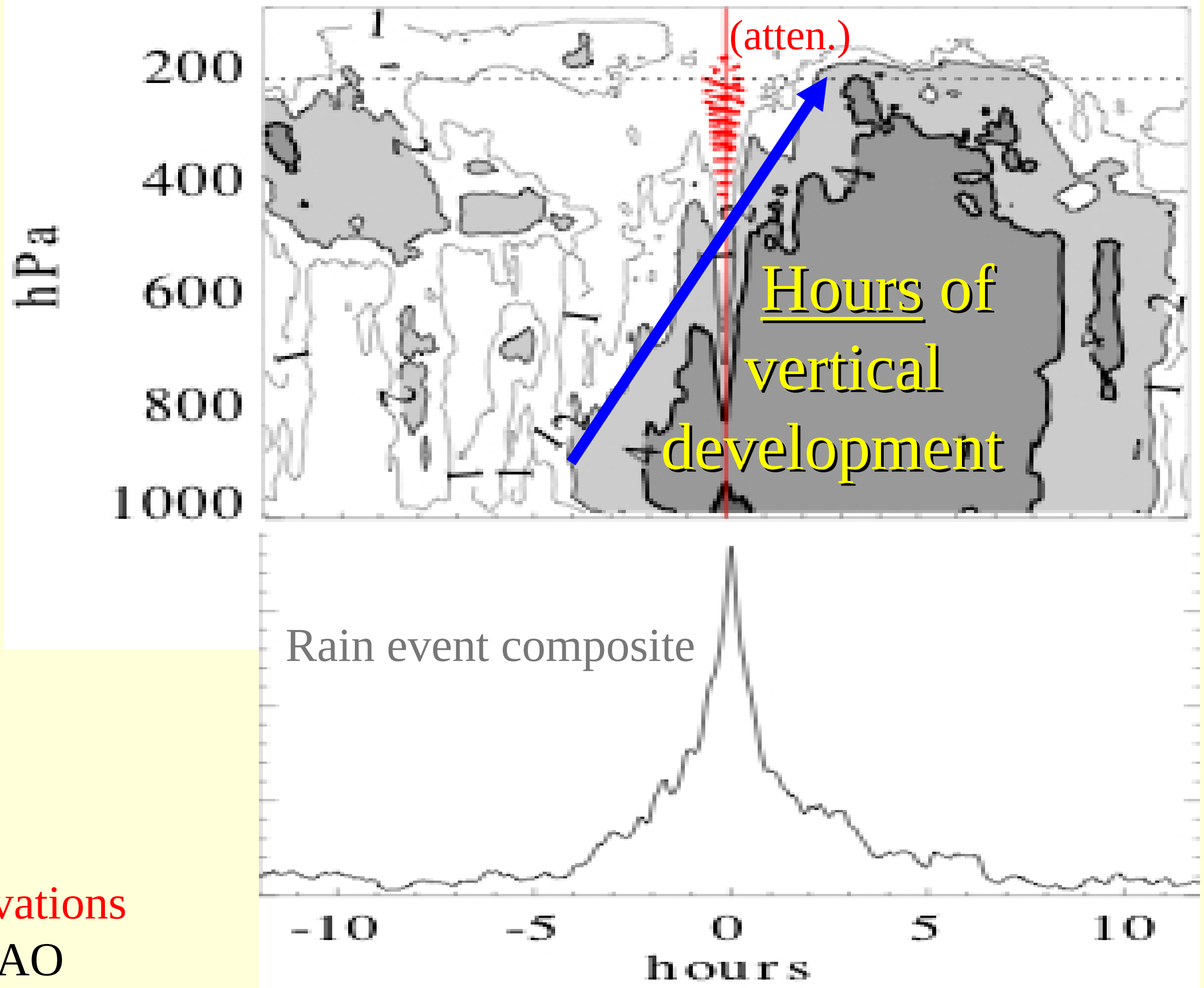
2 meanings of convective "organization"

1. Subgrid (mesoscale): hours to develop
2. Large-scale (days): grid column has to participate correctly
    - Sensitivities, impacts.



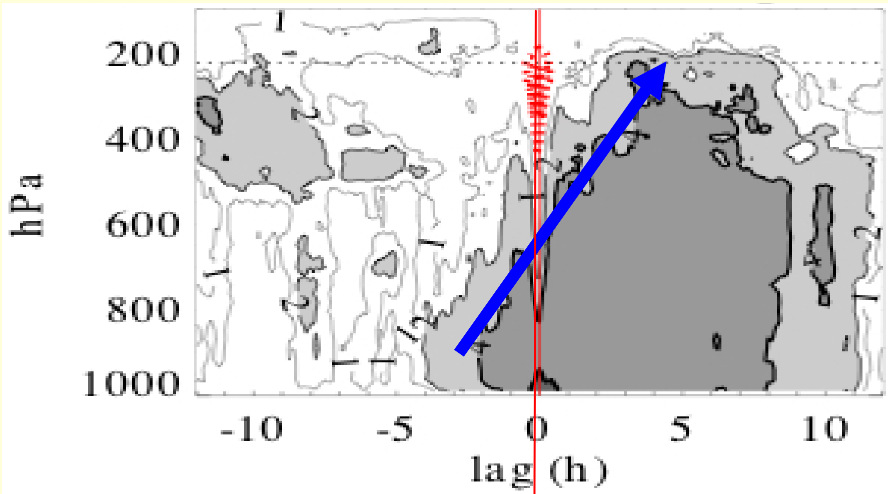
Subgrid (meso) org development

Cloud radar
echo
coverage
regressed
against
surface
rainrate



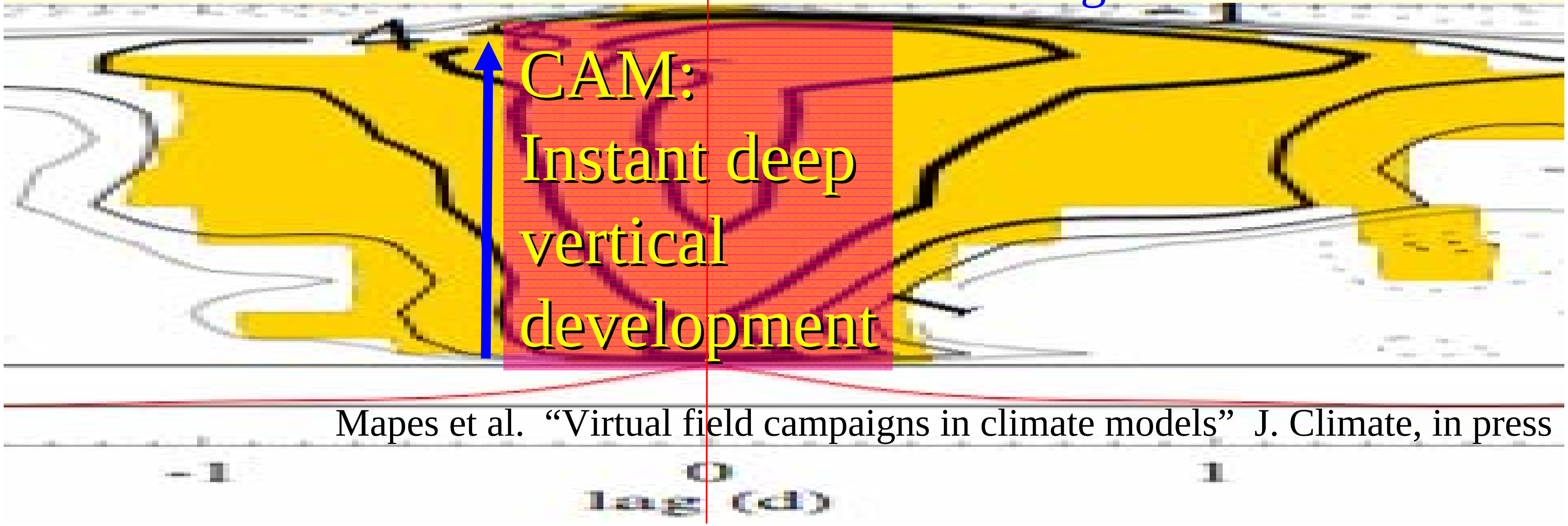
EPIC 5’ point observations
Mapes et al. 2006 DAO

Param. lacks development delay



Cloud radar
echo fraction
Obs (point)

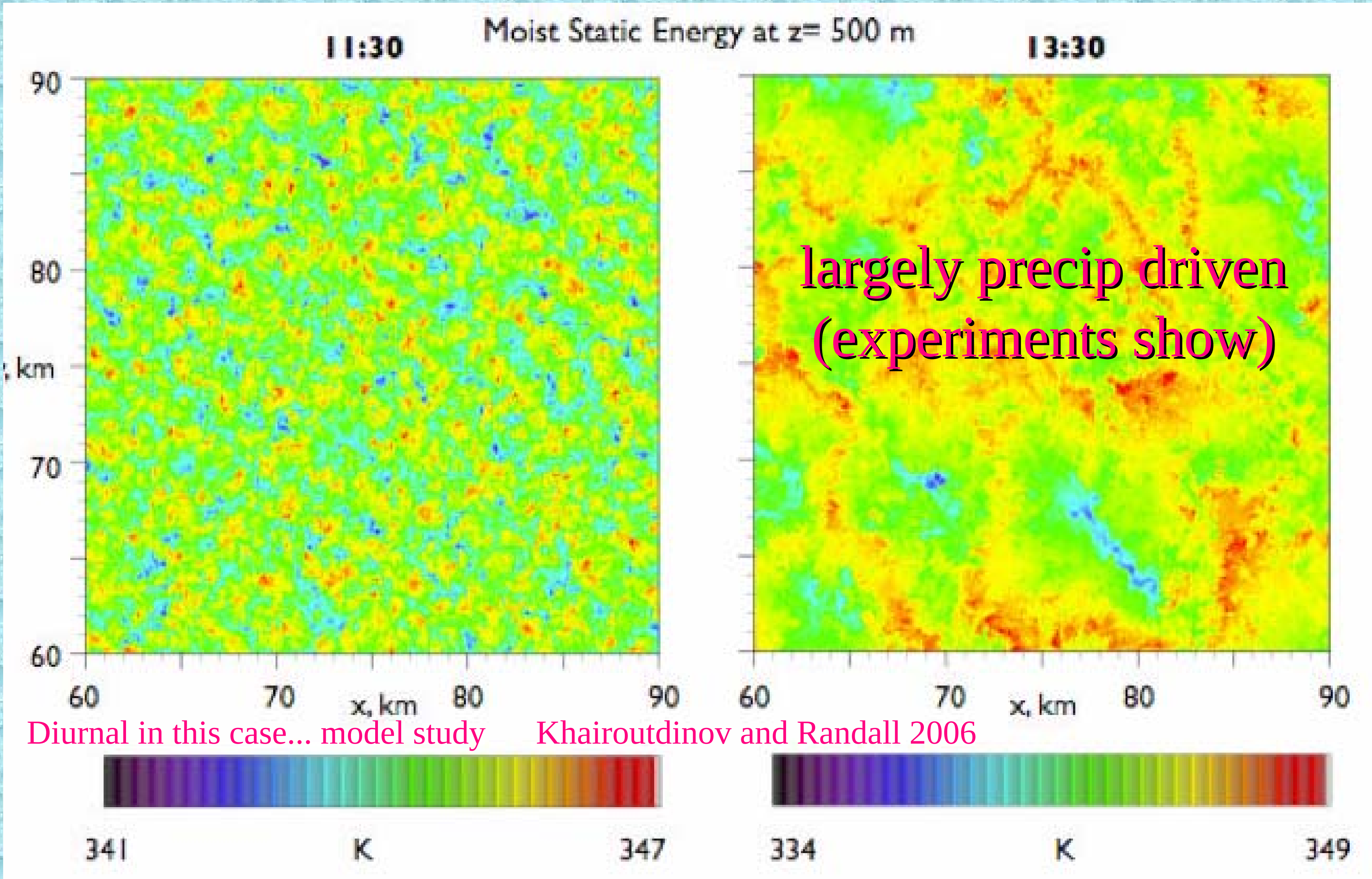
Similar treatment of CAM T42 grid cell cloud fraction



Mapes et al. "Virtual field campaigns in climate models" J. Climate, in press

What takes the time?

”Organization”



largely precip driven (experiments show)

Diurnal in this case... model study

Khairoutdinov and Randall 2006

What I did for summer vacation (2007)

- "org" as local postive feedback on precip in CAM. 2 steps: 1. what makes it, 2. what it does

1. $$\frac{\partial(org)}{\partial t} = \alpha P - \frac{org}{\tau}$$

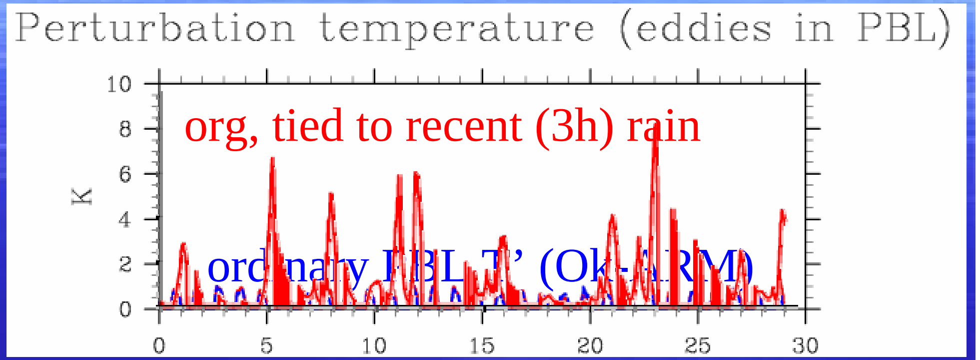
2a. Convective closure entrains moister air (within previous step's convecting layer)

$$q_{entrained} = q_{gridmean} + (org)/5 \times (q_{sat} - q_{gridmean})$$

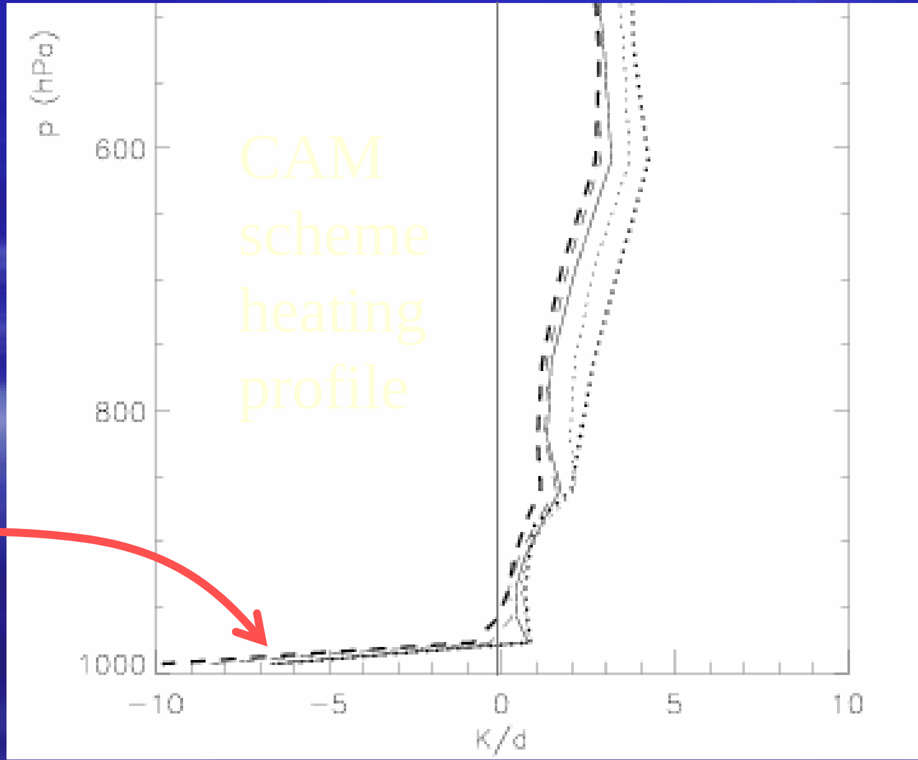
Didn't do enough.
Entrainment too weak in this scheme.

Stronger role for org

$$Tpert = Tpert + org$$



Opposes convection scheme's thin but intense surface cooling by (its version of) downdrafts. Counters inappropriate poisoning of (t+20') updrafts with outflow.

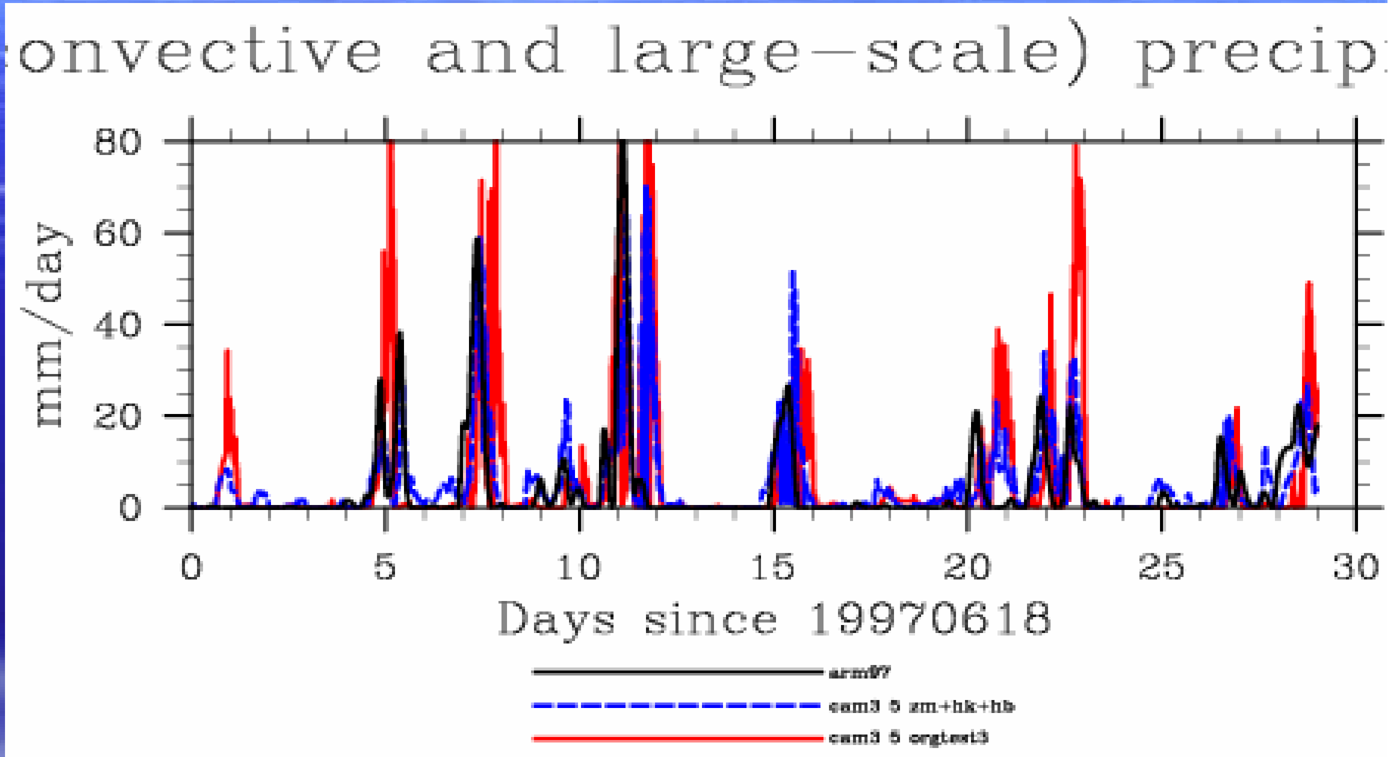


What is org?

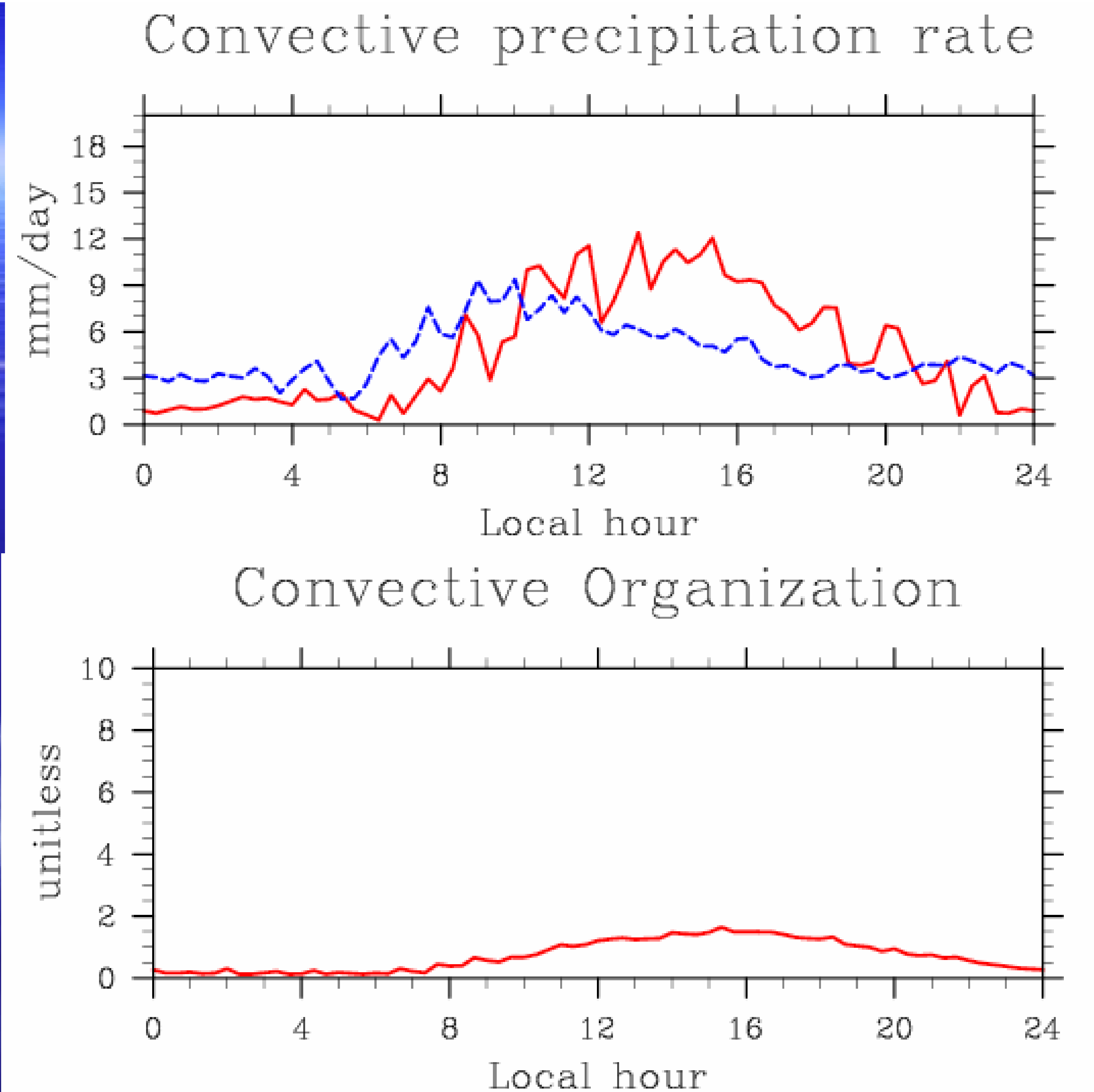
- Operational def: “that which is caused by P, tends to decay over hours, and enhances convective triggering relative to the existing assumption that all convective impacts are homogenized over the grid box instantly”
- Representing:
  - outflow cold pools/ gust fronts the obvious part
  - but broader: all convection-sustaining structures
    - such as vertically aligned moist buoyant rising columns of air large enough to resist entrainment
      - structure in joint distributions of T,q,w if you’re a statistician

Single column model tests

- When it rains, it pours... (increased variance)

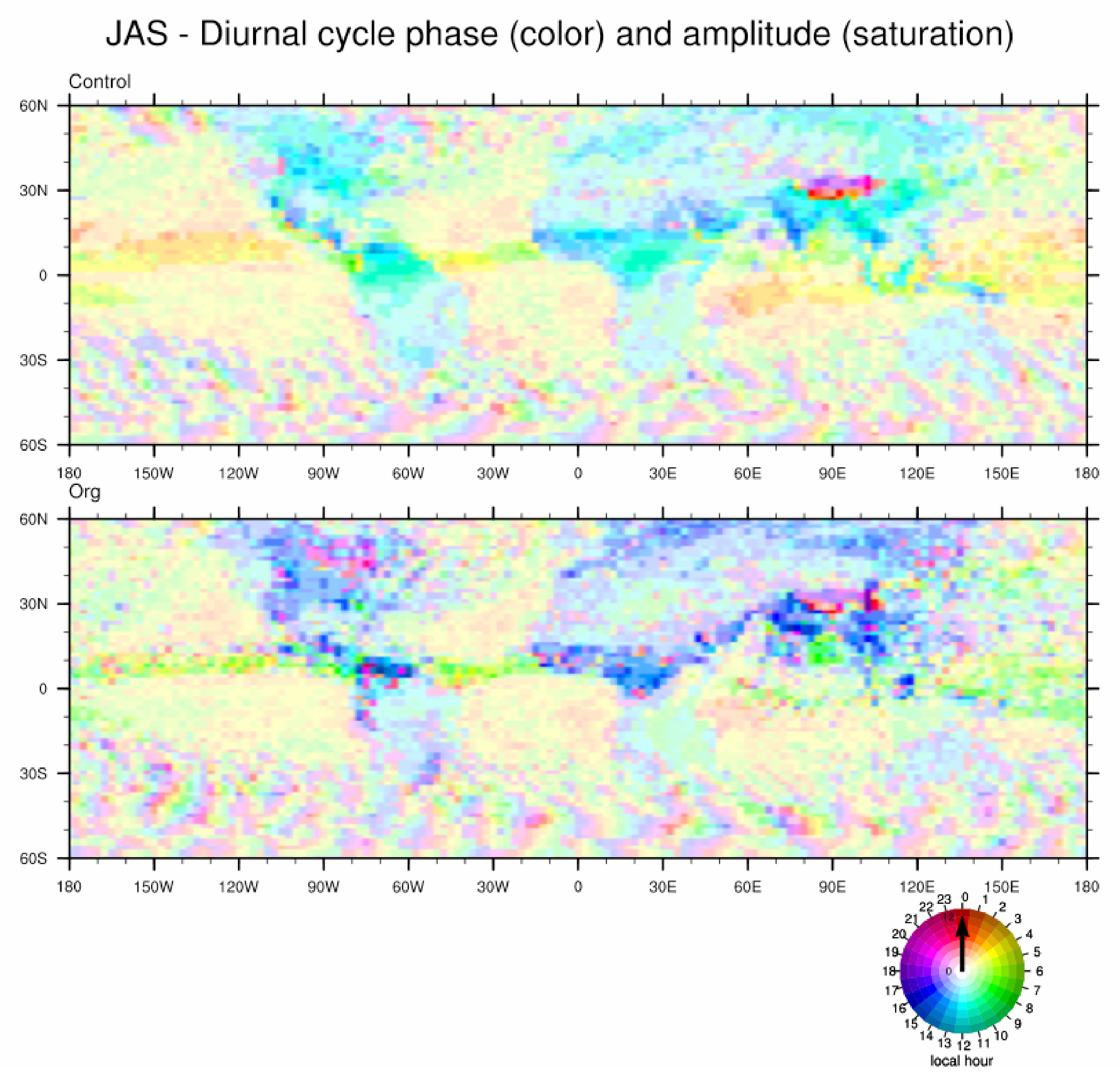


- Diurnal delay as expected (tau = 3h) in SCM



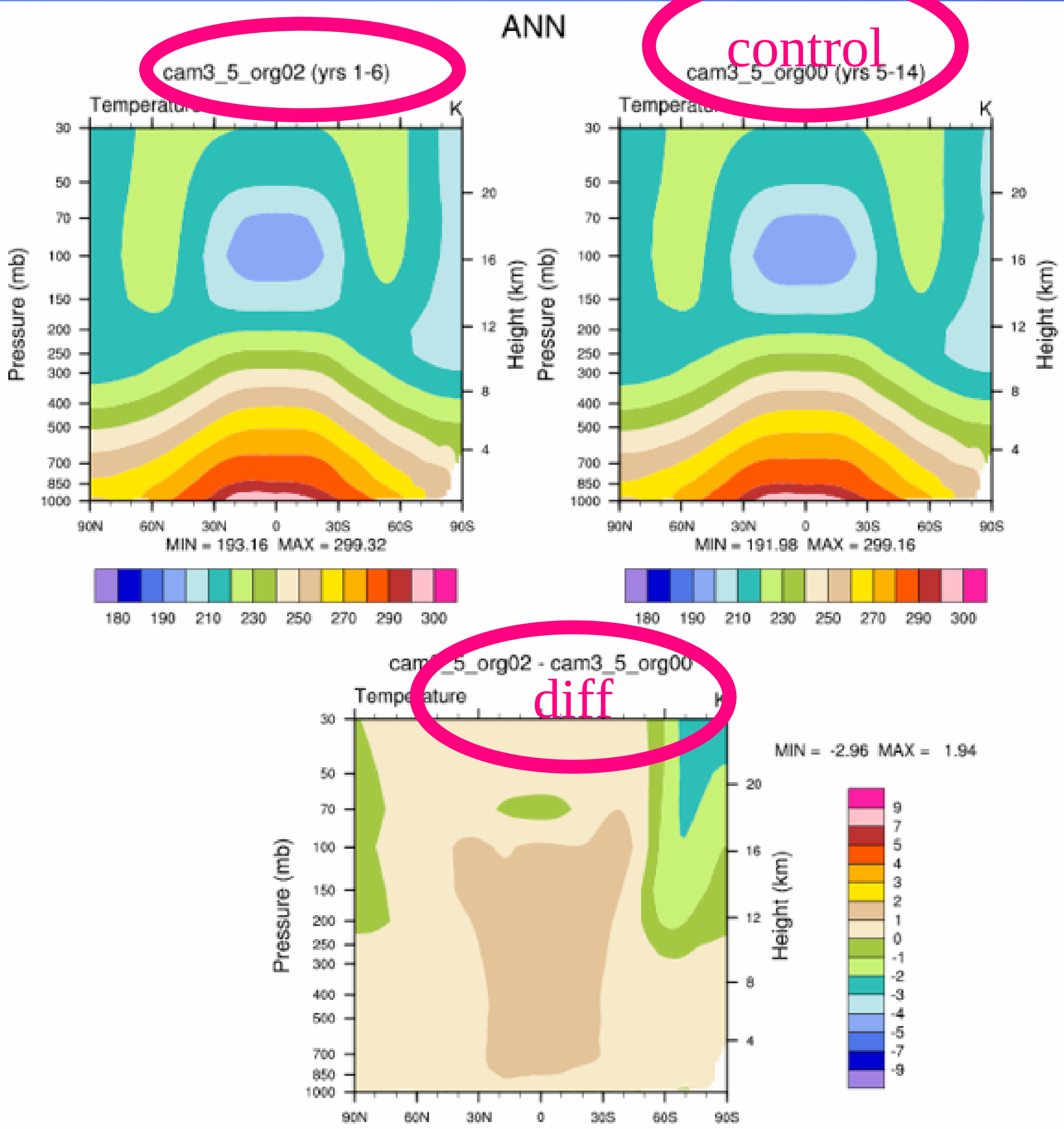
diurnal delay (rather by construction)

- Carries over to full 3D model too



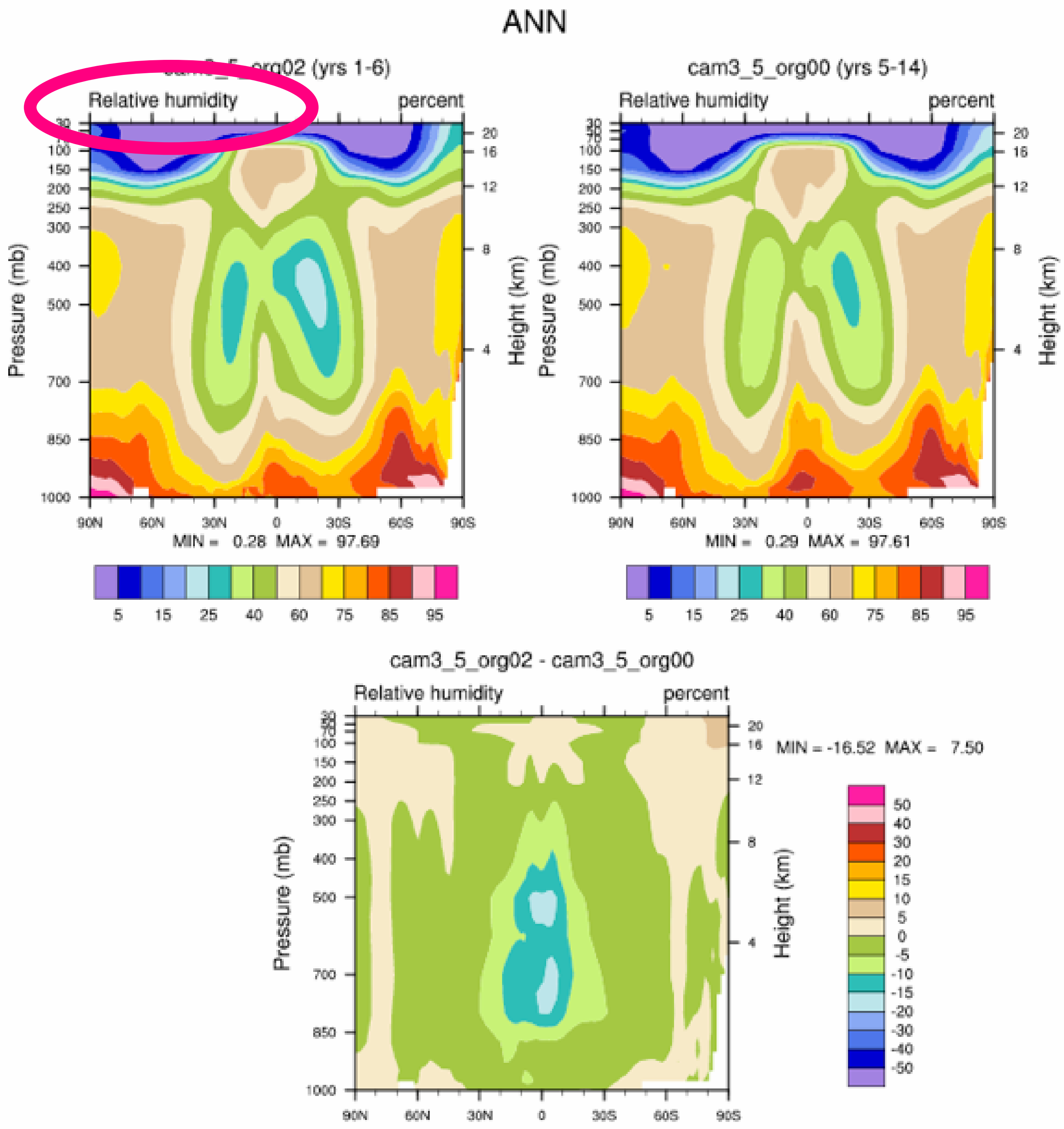
What does it do? Mean state

- Mean state can be more stable (warmer aloft) since convection is happening in org-enhanced areas



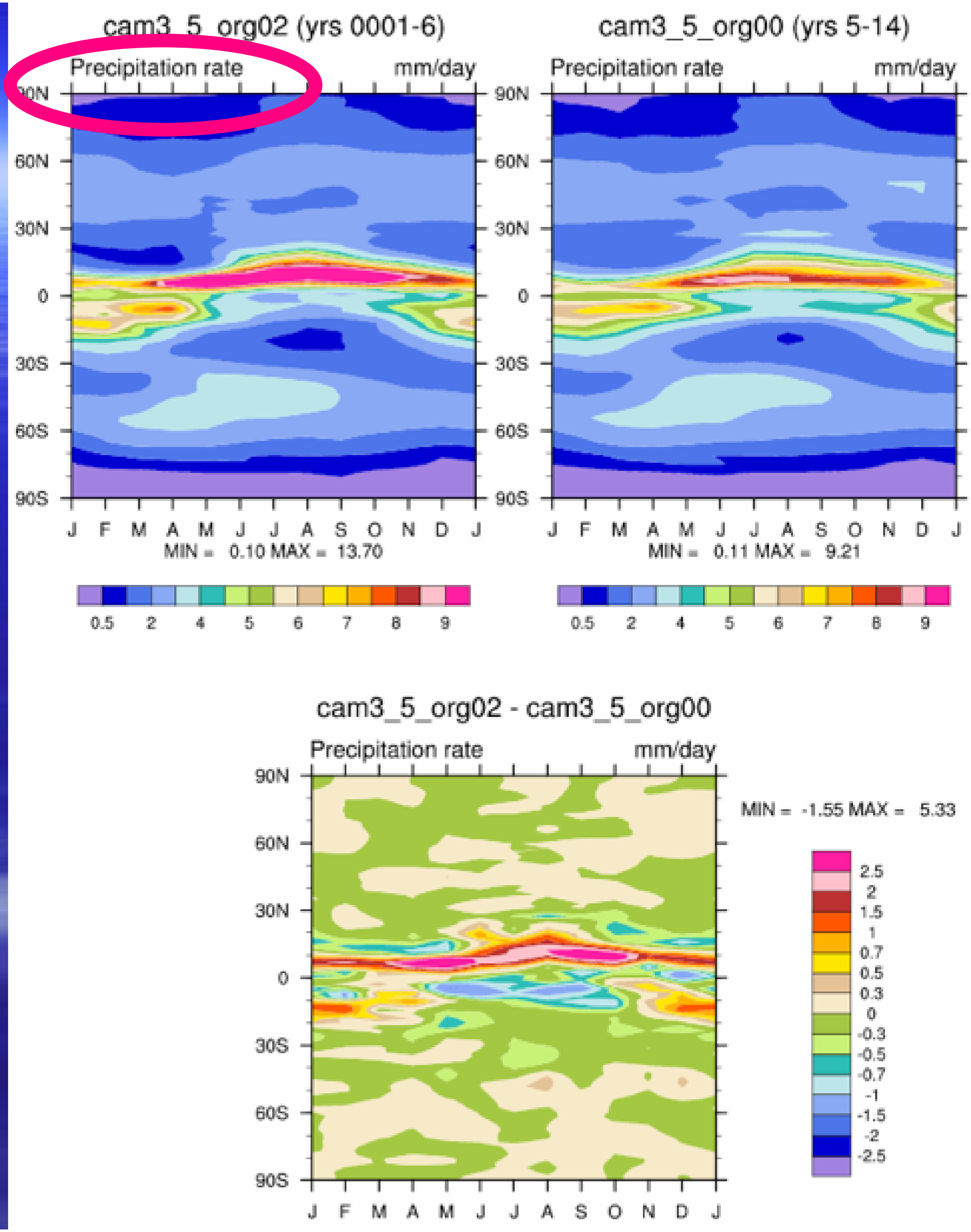
Mean state effects

- Drier, since deep convection is occurring in special org-enhanced places and is buffered from entrainment



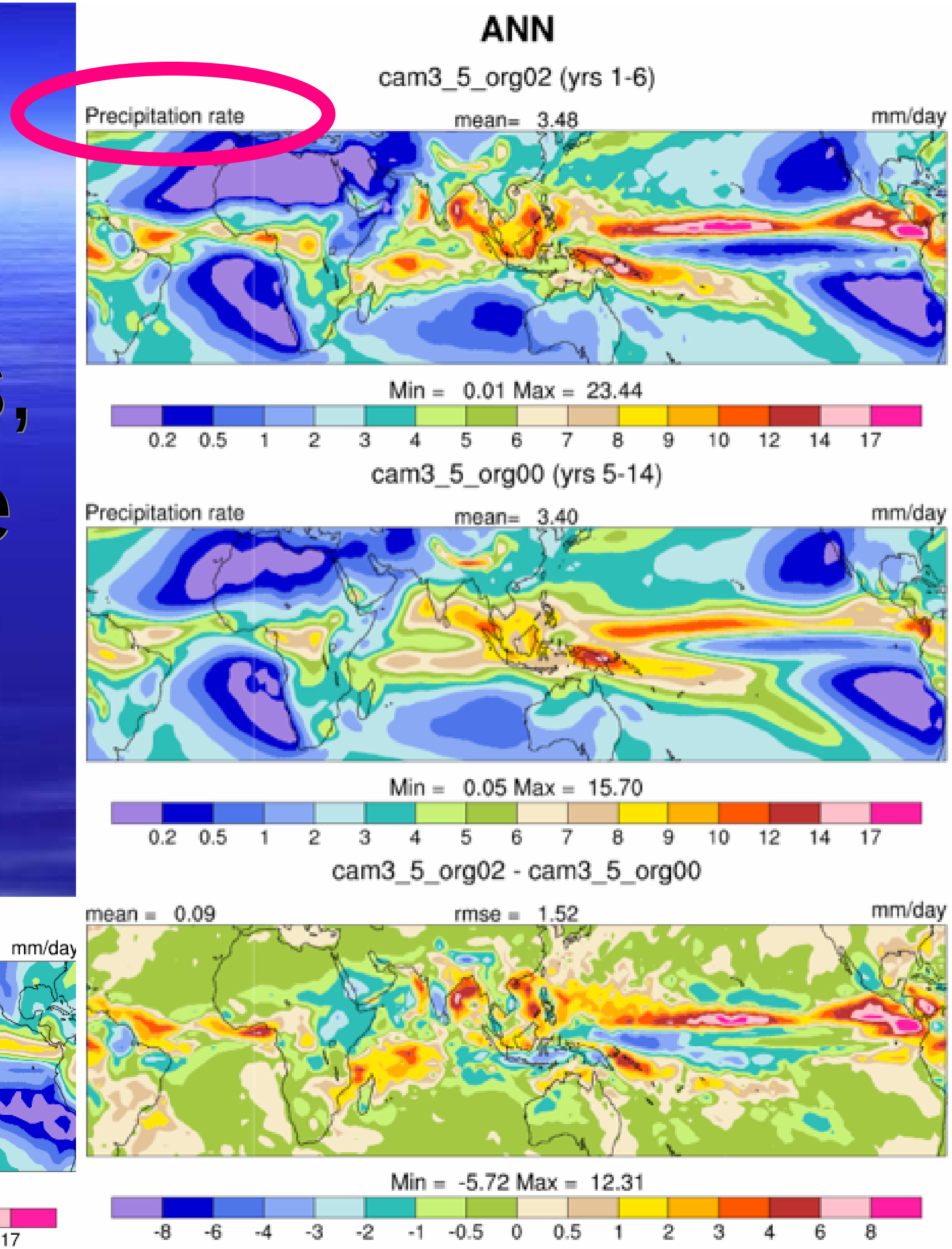
Variability

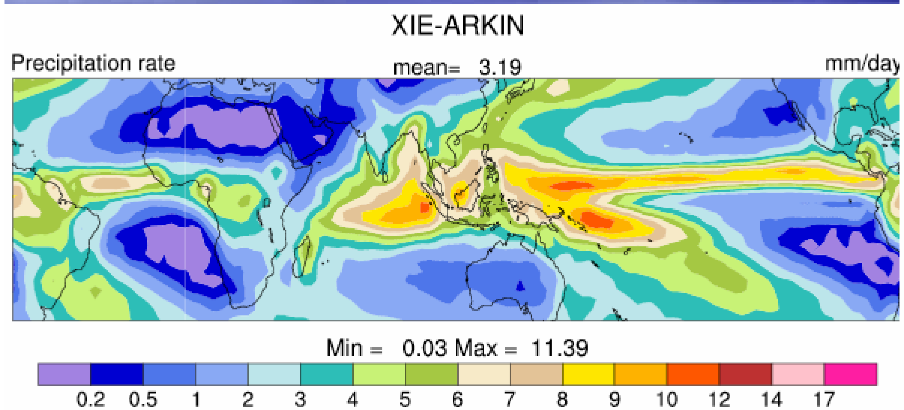
- When it rains, it pours



Variability

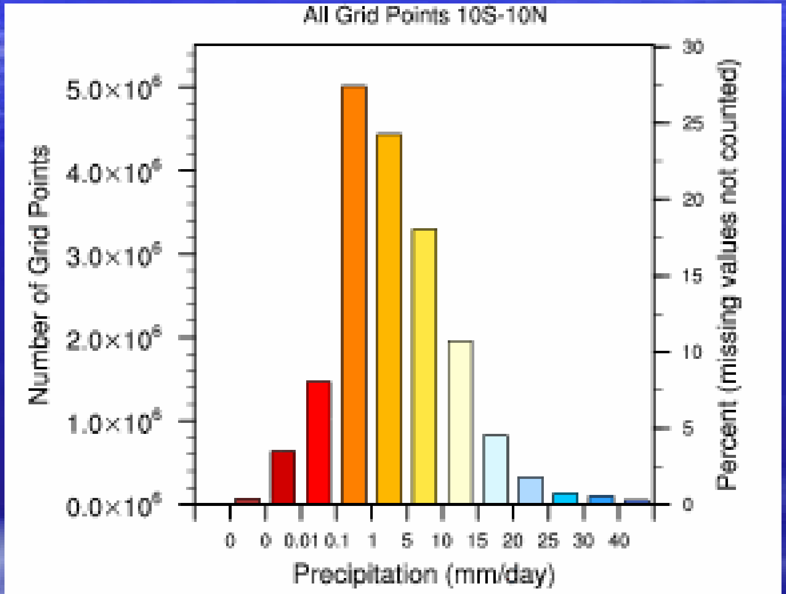
- Where it rains, it pours (& the converse)



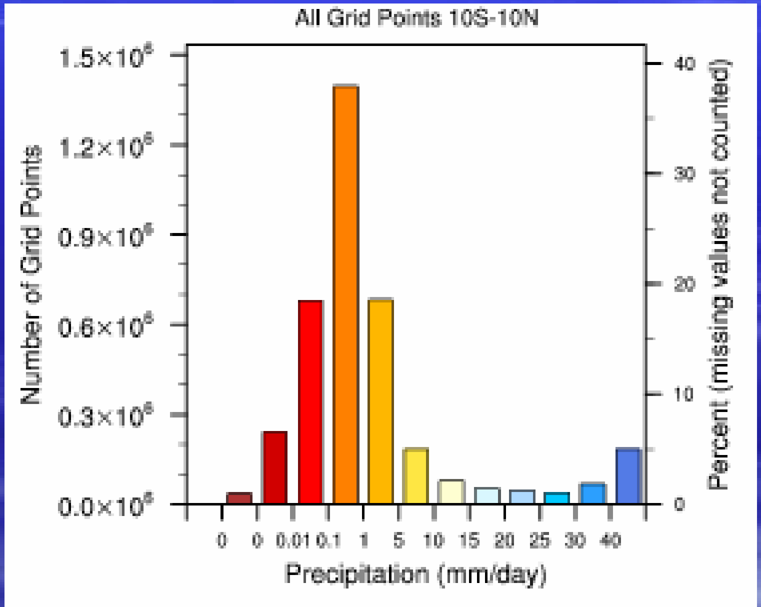


PDF viewpoint

reference CAM



with ORG



A cultural question

What's the most satisfying basis for (in the case of convection) the necessary entrainment, triggering, & persistence tricks?

sciencey
looking
derivations

heuristic
story telling about
familiar phenoms

engineeringy
curve fitting

Conclusions 1

1. Coupled **wave-convection phenomena exist**
   - in tropics at many scales; midlatitudes too
2. **Simulable with explicit convection** models
   - So expensive! Can't we learn to parameterize?
3. Some serious **untapped predictability**
   - ~2 weeks for LS Kelvin waves as well as MJO
4. Ingredients:
   1. **6-8 cloud types**: tower-layer; low-middle(2)-high
   2. **shallow-deep-strat progression**: many time scales
      - orchestrated by waves
        - but how exactly?

Conclusions 2

1. **Dipole vertical mode** crucial to waves
2. there is **no fundamental driving** (e.g. radiative) for this mode
   - no wonder models vary: **depends on subgrid cloudy convection processes**
   - shallow precipitating convection **(congestus) and strat rain drive it (+/-)**
   - being more common / earlier in progression, **congestus may be the key**
     - but how to get them, given deep destabilization (& inst'y) profiles?
3. do these waves propagate or grow **via q, not just T**?
   - CRM convection exhibits ~ 60% - 40% q-T sensitivity ratio
     - plus rather strong **nondeterministic** component...subgrid initial condition dep.
4. Tactics for progress:
   1. **Param: need tricks**
      1. **nonconstant ε** needed in 'plume' treatment, for cg & sensitivity to q
      2. **subgrid convective structure develops/persists over many time steps**
         - call it "org"? "CKE"? tie to prognostic LS variable? store/run full CRM? (MMF)
           - **cultural** question lurks: **engineering** the most honest story to tell?
   2. Testing: Kuang CRM-tested '**parameterized LSD**' method soon (GCSS)!